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USING HOUSEHOLD SURVEY DATA TO EXPLORE THE EFFECTS OF IMPROVED HOUSING CONDITIONS ON MALARIA INFECTION IN CHILDREN IN SUB-SAHARAN AFRICA

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Using Household Survey Data to Explore the Effects of Improved Housing Conditions on Malaria Infection in Children in Sub-Saharan Africa

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Abstract

In the past decade, malaria control strategies in sub-Saharan Africa have focused on the use of insecticide-treated nets (ITNs), indoor residual spraying (IRS), and prompt diagnosis and treatment in combatting malaria. Improved housing can act as a barrier, preventing mosquito entry into homes, and thereby serving as a supplement to insecticides and antimalarial drugs. Evidence of the effectiveness of improved housing on malaria control in endemic tropical countries has been mounting; however, few studies have been attempted on a large scale or have produced findings likely to be generalizable to a broad population. This analysis examines data from 29 nationally representative Demographic and Health Surveys (DHS surveys) and Malaria Indicator Surveys (MIS surveys) from 21 malaria endemic countries in sub-Saharan Africa. Logistic regression was used in both survey-specific and pooled meta-analyses to assess whether improved flooring, wall, and roofing construction materials protected against malaria infection. The models were adjusted to control for potential confounders. This study shows that improved house construction may be an effective malaria control intervention, as it is associated with reduced risk of malaria infection in young children; however, the direction and strength of effect varied by household feature and by setting. Results corroborate findings from other studies that show improved housing as an important predictor of malaria. Findings suggest that investments in improved housing may contribute to sustainable development goals by conferring protection against malaria in addition to other socioeconomic benefits.

1. Introduction

The investments made in insecticide-treated net (ITN) distribution, indoor residual spraying (IRS), and prompt diagnosis and treatment of malaria infections have prevented 633 million malaria cases since 2001 and have averted 4.3 million deaths (WHO 2015a). Despite these significant gains, 214 million cases of malaria occurred worldwide last year (2015) and 438,000 people died of the disease (WHO 2015b). In the World Health Organization (WHO) document "Action and Investment to Defeat Malaria 2016–2030: For a Malaria-Free World," the Roll Back Malaria Partnership outlined goals of a 90% reduction in malaria incidence and malaria mortality from the 2015 levels by 2030 (WHO 2015b). Achieving these goals will demand not only sustained investment in current interventions but also will require innovative and collaborative efforts beyond the existing approaches.

Further reductions in malaria morbidity and mortality may require complementary interventions that do not rely on insecticides, given growing evidence of resistant mosquitoes (Cohen et al. 2012). To date, vector resistance to at least one class of insecticides has been reported in over two-thirds of malaria endemic countries, with pyrethroid resistance being the most prevalent (WHO 2012). Given the current reliance on pyrethroids for vector control, widespread resistance could reduce current gains in malaria control by over half (WHO 2012). Parasite resistance to antimalarial drugs is also a significant problem threatening the long-term effectiveness of medication-based interventions. Artemisinin resistance in the Greater Mekong region is a prime example (WHO 2016).

Due to the indoor, night-biting behaviors of malaria vectors, interventions that prevent mosquito entry into homes have proved an effective supplement to insecticides and antimalarial drugs for malaria control. After the role of the mosquito vector in malaria transmission was identified in 1897, interventions focused on reduction of vector populations or vector-human interactions such as screening. Historical evidence of the role of housing improvements and improved socioeconomic conditions in successful malaria control exists from the United States and Europe (Bruce-Chwatt and de Zulueta 1980; Celli 1901; Garcia-Martin 1972; Hackett and Missirolli 1932). Army barracks in Pakistan, India, and Spain experienced enormous declines in malaria incidence after installing screens (Anderson, Simpson, and Stephens 2014). In many parts of the world, screening played a major role in the elimination of malaria (Lindsay, Emerson, and Charlwood 2002).

More recently, evidence has been mounting of the effectiveness of improved housing on malaria control in endemic tropical countries. Studies have shown protective effects of ceilings and closed eaves, as well as screened windows. In The Gambia, installation of ceilings reduced house entry by *Anopheles gambiae* by 59-80% (Lindsay et al. 2003). A similar intervention in western Kenya installed papyrus mat ceilings below open eaves of traditional homes with a small ITN fixed into the ceiling as a decoy. Results show 76%-82% reductions in indoor *A. gambiae* populations and 86% reductions in *A. funestus* compared with controls (Atieli et al. 2009). Kirby and colleagues found a 59% reduction in *A. gambiae s.l.* in houses with full screens and a 47% reduction in houses with screened ceilings in The Gambia. Significant reductions in anemia prevalence were also observed among children in the intervention houses (Kirby et al. 2009).

Other observational studies have shown protective effects of improved house construction. A study in Sri Lanka showed that residents of houses with completed construction, brick or plaster walls, and a tiled roof had decreased malaria incidence compared with residents of the poorest type of housing (Gamage-Mendis et al. 1991). In another Sri Lankan study, malaria incidence was 2.5 times higher among residents of poorly constructed homes (defined as being incomplete and/or having mud walls and coconut palm thatch roofs compared with plastered brick walls and tiled or corrugated iron roofs) (Gunawardena 1998). In Uganda, children living in houses with metal roofs and brick or concrete walls had 56% lower odds of malaria compared with those in houses with traditional thatched roofs, mud walls, and open eaves (Wanzirah et al.

2015). Synman and colleagues showed that living in a modern house (non-earth floors, non-thatched roofs and non-mud walls) was associated with a reduction in malaria incidence of almost one-half compared with living in a traditional house (Snyman et al. 2015). Indoor vector populations have also been shown to be significantly lower in houses with higher-quality construction. In a study in Tanzania, for example, houses constructed with the highest quality (as determined by a nine-component score) had significantly lower vector density and lower malaria incidence than the lowest-quality houses (Liu et al. 2014). Also, Wanzira and colleagues observed a 52% reduction in the human-biting rate in modern houses compared with traditional houses (Wanzirah et al. 2015).

Individual elements of housing construction have also been shown to affect vector densities and to be associated with malaria risk. Sealed walls (often brick) and metal roofs in particular have been associated with reductions in indoor vector populations (Ernst et al. 2006; Lindsay et al. 2003; Lwetoijera et al. 2013; Sintasath et al. 2005; Wanzirah et al. 2015; Yé et al. 2006), as well as lower malaria incidence (Coleman et al. 2010; Gamage-Mendis et al. 1991; Mmbando et al. 2011; Roberts and Matthews 2016; Yé et al. 2006)

The Roll Back Malaria Vector Working Group recently reviewed the evidence on housing and malaria and concluded that strong evidence exists supporting the protective effect of 'modern' housing in many tropical countries. The consensus report issued by the group highlighted the importance of closed eaves, ceilings, and window and door screening, as well as construction features such as metal roofs and improved or finished walls, as examples of housing conditions conferring protection against malaria (Vector Control Working Group-Roll Back Malaria 2015).

Few studies have examined the effect of housing conditions on malaria risk in large samples or across countries. One recent meta-analysis by Tusting and colleagues estimated the odds of malaria infection associated with modern housing combining results of case-control, cross-sectional, and cohort studies (Tusting et al. 2015). The studies included in this meta-analysis come from a wide range of countries spanning multiple continents and a wide range of study years (from 1939 to 2015), which likely contributed to the significant heterogeneity and limited the generalizability of findings. In order to produce more representative and reliable results, the present study makes use of publicly available, nationally representative data from Demographic and Health Surveys (DHS surveys) and Malaria Indicator Surveys (MIS surveys). Both surveys are an untapped resource for analysis of the links between housing type and malaria infection. They include standard survey questions on housing construction with questions about floor, wall, and roof materials. Most MIS surveys and many DHS surveys in malaria-endemic countries also contain data on malaria infection status in young children; the datasets include results of rapid diagnostic tests (RDTs) and sometimes results of microscopy readings of blood slides to detect malaria parasites in children age 6-59 months. DHS and MIS surveys use standard methods to calculate socioeconomic indicators and other variables that may be important confounders of the association between housing and malaria infection. Exploring these resources, the present study looks at national-level associations between house construction and malaria infection in children age 6-59 months across a wide range of countries from sub-Saharan Africa, controlling for potential confounders.

2. Methods

2.1. Data

This analysis uses data from the DHS and MIS surveys, which are nationally representative, population-based household surveys. All survey data are available at www.dhsprogram.com. The analysis examines 21 malaria endemic countries in sub-Saharan Africa using 29 DHS and MIS surveys with data on malaria parasitemia status in children age 6-59 months and housing characteristics such as type of flooring, wall, and roofing materials (Figure 1).

Figure 1. Countries included in analysis

The time period for this analysis is from 2007 to 2015 (Figure 2). The first DHS/MIS survey that included malaria parasitemia testing was in 2006, but it was not until the following year that a survey included both parasitemia data and data on housing characteristics such as floor, wall, and roofing materials.

Figure 2. Timeline of available survey data

2.2. Study Population

The study population for the analysis is children age 6-59 months who stayed in surveyed households the night before the survey who were tested for malaria parasitemia. Malaria parasitemia testing in this population was conducted by microscopy and rapid diagnostic test (RDT).

2.3. Study Variables

2.3.1. Outcome: Parasite prevalence

The definition of parasite prevalence is the number of children age 6-59 months with malaria infection detected by a rapid diagnostic test or microscopy out of the total number of children age 6-59 months tested for malaria parasites by rapid diagnostic test or microscopy. The parasite prevalence among children age 6-59 months is an indicator of malaria burden within populations and provides a guide to the level of malaria transmission. All countries studied used malaria microscopy values for the analysis except Cameroon DHS 2011, Ghana DHS 2014, and Tanzania HMIS 2007-08. These countries only tested for malaria parasitemia using RDT. The type of RDT varied across surveys according to the official RDT guidelines for the country at the time of the survey implementation.

It is important to note that parasite prevalence can fluctuate dramatically throughout the course of a year with the seasonal patterns of malaria transmission, and thus the timing of a survey in relation to peak transmission may influence values of the indicator. Seasonality may also influence sleeping behaviors (sleeping outdoors to avoid heat, going indoors late, leaving windows open, etc.) thus it may confound the association between housing characteristics and risk of malaria infection. MIS surveys are conducted during peak malaria transmission, which tends to occur within 4-6 weeks of the peak rainy season, due to fluctuations in mosquito populations.

2.3.2. Explanatory variables

Key predictors: Housing characteristics

Housing variables used in the analysis examine the main materials used for the construction of floors, walls, and roofs among the surveyed households. Each housing material is divided into categories of natural, rudimentary, and finished. The interviewer observes and records housing characteristics at the beginning of the household questionnaire. If a variety of different materials is used for either the floor, wall, or roof (i.e., both vinyl and carpet flooring), the interviewer records the material that covers the largest area. At the start of the survey, questionnaires are reviewed and updated to include country specific text/descriptions if needed. Figure 3 shows the model questionnaire for DHS/MIS housing characteristics. Readers will note the absence of questions on other aspects of housing that could influence indoor vector populations, such as the presence of open or closed eaves, screening of windows or doors, and presence of ceilings. This information is not routinely collected in DHS/MIS surveys and therefore is not included in the analysis.

Figure 3. Model questions for housing characteristics

NO.	QUESTIONS AND FILTERS	CODING CATEGORIES	SKIP
142	OBSERVE MAIN MATERIAL OF THE FLOOR OF THE DWELLING. RECORD OBSERVATION.	**NATURAL FLOOR** EARTH/SAND .... 11 DUNG .... 12 **RUDIMENTARY FLOOR** WOOD PLANKS .... 21 PALM/BAMBOO .... 22 **FINISHED FLOOR** PARQUET OR POLISHED WOOD .... 31 VINYL OR ASPHALT STRIPS .... 32 CERAMIC TILES .... 33 CEMENT .... 34 CARPET .... 35 OTHER ________ 96 (SPECIFY)	
143	OBSERVE MAIN MATERIAL OF THE ROOF OF THE DWELLING. RECORD OBSERVATION.	**NATURAL ROOFING** NO ROOF .... 11 THATCH/PALM LEAF .... 12 SOD .... 13 **RUDIMENTARY ROOFING** RUSTIC MAT .... 21 PALM/BAMBOO .... 22 WOOD PLANKS .... 23 CARDBOARD .... 24 **FINISHED ROOFING** METAL .... 31 WOOD .... 32 CALAMINE/CEMENT FIBER .... 33 CERAMIC TILES .... 34 CEMENT .... 35 ROOFING SHINGLES .... 36 OTHER ________ 96 (SPECIFY)	
144	OBSERVE MAIN MATERIAL OF THE EXTERIOR WALLS OF THE DWELLING. RECORD OBSERVATION.	**NATURAL WALLS** NO WALLS .... 11 CANE/PALM/TRUNKS .... 12 DIRT .... 13 **RUDIMENTARY WALLS** BAMBOO WITH MUD .... 21 STONE WITH MUD .... 22 UNCOVERED ADOBE .... 23 PLYWOOD .... 24 CARDBOARD .... 25 REUSED WOOD .... 26 **FINISHED WALLS** CEMENT .... 31 STONE WITH LIME/CEMENT .... 32 BRICKS .... 33 CEMENT BLOCKS .... 34 COVERED ADOBE .... 35 WOOD PLANKS/SHINGLES .... 36 OTHER ________ 96 (SPECIFY)	

Table 1 summarizes the different types of housing characteristics found across the countries included in the analysis. The survey questionnaire classifies housing characteristics as natural, rudimentary, and finished.

Table 1. Housing characteristics summary

	Flooring Types	Wall Types	Roof Types
Natural	Earth, sand, clay, mud Dung	No wall Cane/palm/trunks Dirt Mud and sticks Tin/cardboard/paper/ bags Thatched/straw	No roof Grass/thatch/palm leaf Sod Straw
Rudimentary	Tablets/wood planks Palm, bamboo Mat Adobe	Bamboo with mud Stone with mud Uncovered adobe Plywood Cardboard Reused wood Trunks with mud Unburnt bricks Unburnt bricks with plaster Unburnt bricks with mud	Rustic mat Palm/bamboo Wood planks Cardboard Tarpaulin, plastic
Finished	Parquet, polished wood Vinyl, asphalt strips, floor mat, Linoleum Ceramic tiles, mosaic Cement Carpet Stone Bricks	Cement Stone with lime/cement Bricks Cement blocks Covered adobe Wood planks/shingles Burnt bricks with cement	Metal Wood Calamine/cement fiber Ceramic tiles Cement Roofing shingles Asbestos/slate roofing sheets

Table 2 shows the categorization of unimproved and improved housing materials. In this analysis natural and rudimentary wall and roofing types are considered unimproved, while only natural flooring is considered unimproved. For improved materials, rudimentary and finished flooring are categorized as improved, while improved walls and roofs are only those listed under the finished category. The improved categories for floor, wall, and roof types are used throughout the analysis.

Table 2. Unimproved and improved housing materials summary

	Flooring Types	Wall Types	Roof Types
Unimproved Materials	Earth, sand, clay, mud Dung	No wall Cane/palm/trunks Dirt Mud and sticks Tin/ cardboard/ paper/ bags Thatched/straw Bamboo with mud Stone with mud Uncovered adobe Plywood Cardboard Reused wood Trunks with mud Unburnt bricks Unburnt bricks with plaster Unburnt bricks with mud	No roof Grass/thatch/palm leaf Sod Straw Rustic mat Palm/bamboo Wood planks Cardboard Tarpaulin, plastic
Improved Materials	Tablets/wood planks Palm, bamboo Mat Adobe Parquet, polished wood Vinyl, asphalt strips, floor mat, Linoleum Ceramic tiles, mosaic Cement Carpet Stone Bricks	Cement Stone with lime/cement Bricks Cement blocks Covered adobe Wood planks/shingles Burnt bricks with cement	Metal Wood Calamine/cement fiber Ceramic tiles Cement Roofing shingles Asbestos/slate roofing sheets

The analysis also includes comparison of housing characteristics by a composite measure: Modern housing is defined as having improved floor, wall, and roof construction, while traditional housing is a composite of unimproved floor, wall, and roof construction.

Covariates: All potential confounders

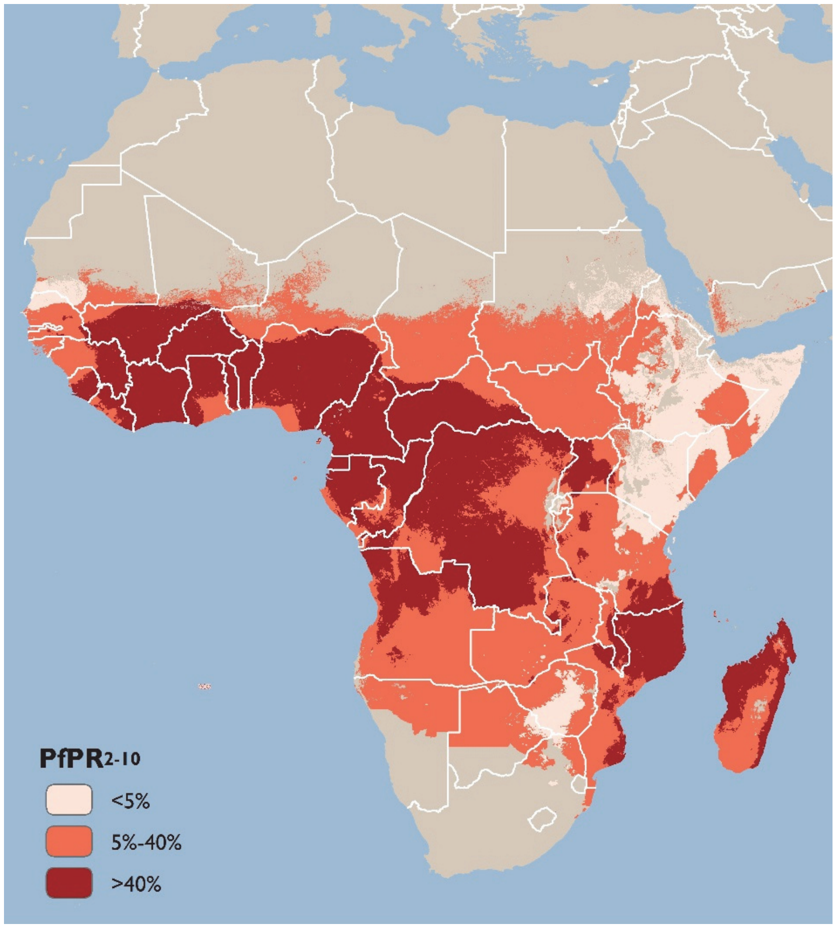
For the purpose of this analysis, variables found in the literature related to parasitemia and housing characteristics were reviewed and included, based on data availability (Table 3). The DHS wealth index is a survey-specific measure of the relative economic status of households based on an analysis of household assets and service amenities at a particular point in time. The asset-based wealth index places individual households on a continuous scale of relative wealth generated by using principal components analysis. Individuals are ranked according to the standardized score of the household in which they reside, and then the sample is divided into quintiles. Each survey has a single asset index that is relevant only for that population during the time period of the survey. The DHS wealth indices are not comparable across countries or over time; they are a cross-sectional measure of relative wealth (Rutstein 2004). Residence is defined as whether a household is located in a rural or urban area. The child's age and sex (male or female) were also included in the model. Child's age is available as a continuous variable from 6-59 months based on the date of birth and the date of interview. For use in the analyses, this variable was divided into five categories: 6-11 months, 12-23 months, 24-35 months: 36-47 months and 48-59 months. ITN usage (yes/no) is defined as sleeping under an ITN the night before the survey and IRS (yes/no) is categorized as the household being sprayed against mosquitoes in the 12 months preceding the survey. Since IRS spraying is not national policy in all countries, questions on IRS were not included in all surveys; 21 of the 29 surveys included in the analysis contained questions on IRS spraying. All households in surveys without IRS questions were treated as though they did not benefit from this intervention (coded as no).

Table 3. Summary of explanatory variables

Variable	Type	Details of Measurement
Key Predictors		
Improved Floor	Categorical with two categories: yes/no	Improved floor categorized as having a rudimentary (i.e., tablets, mat, adobe) or finished floor (i.e., parquet, carpet, cement, bricks)
Improved Wall	Categorical with two categories: yes/no	Improved wall categorized as having a finished wall (i.e., covered adobe, bricks, cement blocks, wood planks)
Improved Roof	Categorical with two categories: yes/no	Improved roof categorized as having a finished roof (i.e., metal, wood, ceramic tiles, cement, roofing shingles)
Modern House	Categorical with two categories: yes/no	Composite variable of improved floor, improved wall, improved roof
Covariates		
Wealth Index	Categorical with five categories	Asset-based principal component analysis
Residence	Categorical with two categories	Household classified as being in an urban or rural area
Child's Age	Categorical with five categories (months): 6-11, 12-23, 24-35, 36-47, 48-59	Based on date of birth and date of interview
Child's Sex	Categorical with two categories: male, female	Collected from women's interview
ITN	Categorical with two categories: yes/no	ITN used the night before the survey
IRS	Categorical with two categories: yes/no	Household was sprayed against mosquitoes in the last 12 months
Malaria Endemicity	Categorical with three categories: no malaria/low risk, intermediate risk, and high risk	Categorized using Malaria Atlas Project (MAP) $Pf\text{PR}_{2\text{-}10}$ values

Malaria endemicity levels were created using data from the 2010 Malaria Atlas Project (MAP). MAP provides a spatial data layer of age-standardized $Pf\text{PR}_{2\text{-}10}$, describing the estimated proportion of children age 2-10 in the general population that are infected with *P. falciparum* at any one time, averaged over the 12 months of 2010 (Gething et al. 2011). DHS and MIS data include geospatial data for the location of the approximate center of each cluster, thereby permitting linkage of MAP data to survey clusters; thus, all residents of a cluster from the DHS or MIS survey data were assigned the same malaria risk value based on corresponding MAP data. MAP $Pf\text{PR}_{2\text{-}10}$ cut-offs (≤5%, 5%-40%, and >40%) were used to categorize malaria into no malaria/low risk, intermediate risk, and high risk (Figure 4). DHS and MIS cluster locations are displaced to ensure participant confidentiality. Urban clusters are displaced by 0-2 kilometers and rural clusters by 0-5 kilometers, with 1% of rural clusters displaced between 0-10 kilometers. Due to this displacement, linking the survey data with MAP data is not exact.

Figure 4. The spatial distribution of *Plasmodium falciparum* (*Pf*) malaria stratified by endemicity class in 2010 based on *Pf* prevalence rates among children age 2-10



Source: Malaria Atlas Project (Gething et al. 2011)

2.4. Analysis

All analyses were conducted using Stata 14. Household survey data were adjusted for survey design, clustering, and sample weights. The study included a country-level descriptive analysis of housing characteristics and logistic regression analysis. Logistic regression was used in both a survey-specific and a pooled meta-analysis to assess whether improved flooring, wall, and roofing types were protective against malaria. Specific inclusion criteria for the descriptive and regression analysis included:

1. Countries must have had a survey that included parasitemia testing via microscopy or RDT on children under age 5.

2. The survey must have collected data on all three housing characteristics (flooring, wall, and roofing materials).

3. Survey datasets and GIS coordinates for survey clusters were publicly available before June 2016.

In total, 29 surveys in 21 countries were selected for inclusion in the analysis (Table 4). These 29 surveys included 10,288 clusters, of which 31% were categorized in the high-risk category for malaria

(PfPR$_{2\text{-}10}$>40%), 44% in the intermediate-risk category (5%-40%), and 20% in the low-risk category (≤5%). Four percent of the household clusters were dropped from the analysis due to missing GPS coordinates.

Table 4. Countries and surveys included in the analysis

Country	Survey	Dates of Fieldwork
Angola	MIS 2011	01/2011- 05/2011
Benin	DHS 2011-12	12/2011- 03/2012
Burkina Faso	DHS 2010	05/2010- 01/2011
Burkina Faso	MIS 2014	09/2014- 10/2014
Burundi	MIS 2012	11/2012- 01/2013
Cameroon	DHS 2011	01/2011- 08/2011
Congo Democratic Republic	DHS 2013-14	08/2013- 02/2014
Cote d'Ivoire	DHS 2011-12	12/2011- 05/2012
Ghana	DHS 2014	09/2014- 12/2014
Guinea	DHS 2012	06/2012- 10/2012
Kenya	MIS 2015	07/2015- 08/2015
Liberia	MIS 2009	12/2008- 03/2009
Liberia	MIS 2011	09/2011- 12/2011
Madagascar	MIS 2011	03/2011- 06/2011
Madagascar	MIS 2013	04/2013- 06/2013
Malawi	MIS 2012	04/2012- 05/2012
Malawi	MIS 2014	05/2014- 06/2014
Mali	DHS 2012-13	11/2012- 02/2013
Mozambique	DHS 2011	06/2011- 11/2011
Nigeria	MIS 2010	10/2010- 12/2010
Rwanda	DHS 2010	09/2010- 03/2011
Rwanda	DHS 2014-15	11/2014- 04/2015
Senegal	DHS 2010-11	10/2010- 04/2011
Senegal	DHS 2012-13	09/2012- 06/2013
Tanzania	HMIS 2007-08	10/2007- 02/2008
Tanzania	HMIS 2011-12	12/2011- 05/2012
Togo	DHS 2013-14	11/2013- 04/2014
Uganda	MIS 2009	11/2009- 01/2010
Uganda	MIS 2014-15	12/2014- 01/2015

Descriptive analyses were conducted on all available survey data to examine distributions of parasitemia and housing characteristics. Confidence intervals of 95% (95% CI) were calculated around each prevalence estimate. A parallel plot of the percentage of households with improved floor, wall, and roof materials plotted against the pooled median values was created to compare distributions of these three variables across countries.

The study used unadjusted and adjusted logistic regression models to assess whether improved flooring, wall, and roofing types were protective against malaria infection. The adjusted models control for ITN use, IRS spraying in the past 12 months, household wealth status, age of child, sex, and malaria endemicity, in separate survey-specific analyses as well as in a meta-analysis. The association between malaria parasitemia and the three housing characteristics were examined first for each country and survey year independently and then in a meta-analysis using pooled data accounting for random effects at the survey level (using the metan macro in Stata 14.1). Tests for heterogeneity (I^2 tests) were generated to verify that the model sufficiently controlled for differences between surveys.

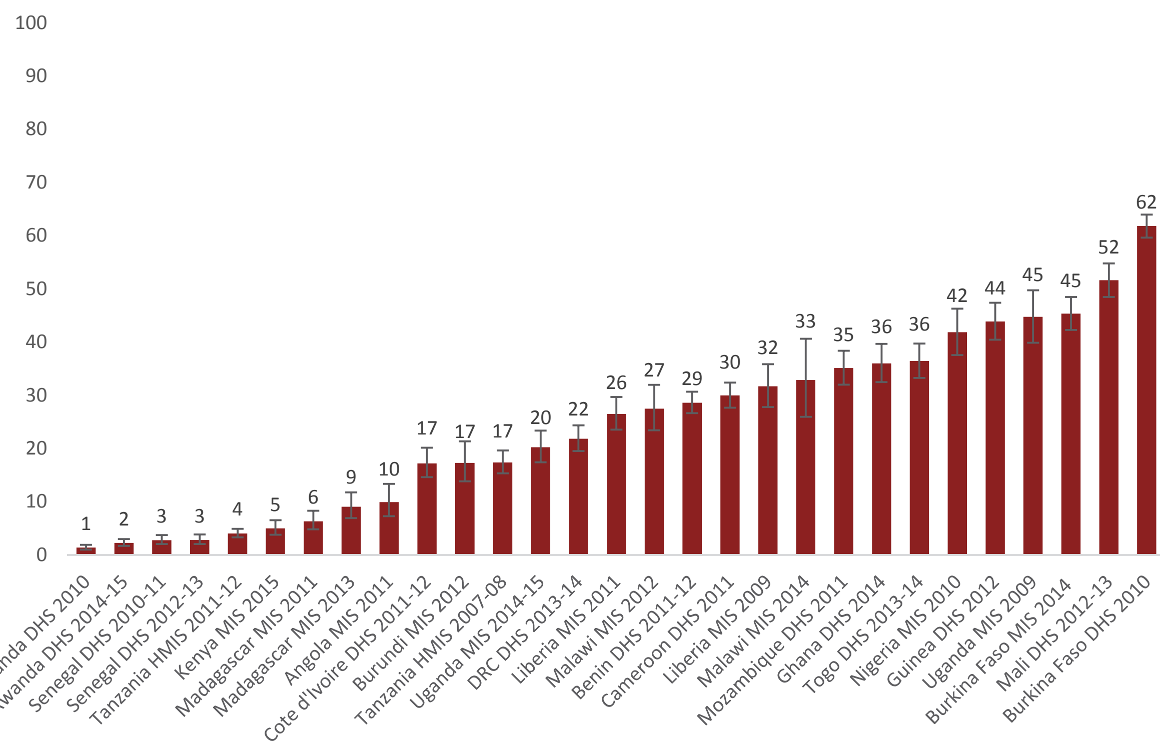
3. Results

3.1. Descriptive Analyses

3.1.1. Malaria parasitemia prevalence

The prevalence of parasitemia in children age 6-59 months ranged from 1% in Rwanda DHS 2010 to 62% in Burkina Faso DHS 2010, among surveys conducted between 2007 and 2015 in which RDT or microscopy measured malaria parasitemia (Figure 5).

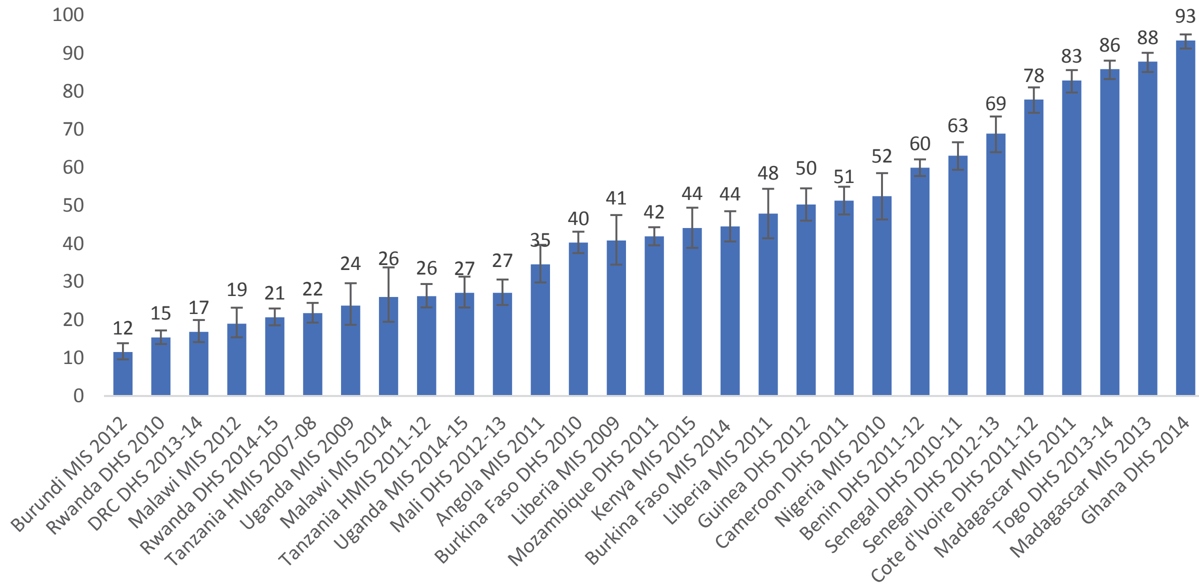
Figure 5. Range of malaria parasitemia prevalence in children age 6-59 months



3.1.2. Housing characteristics

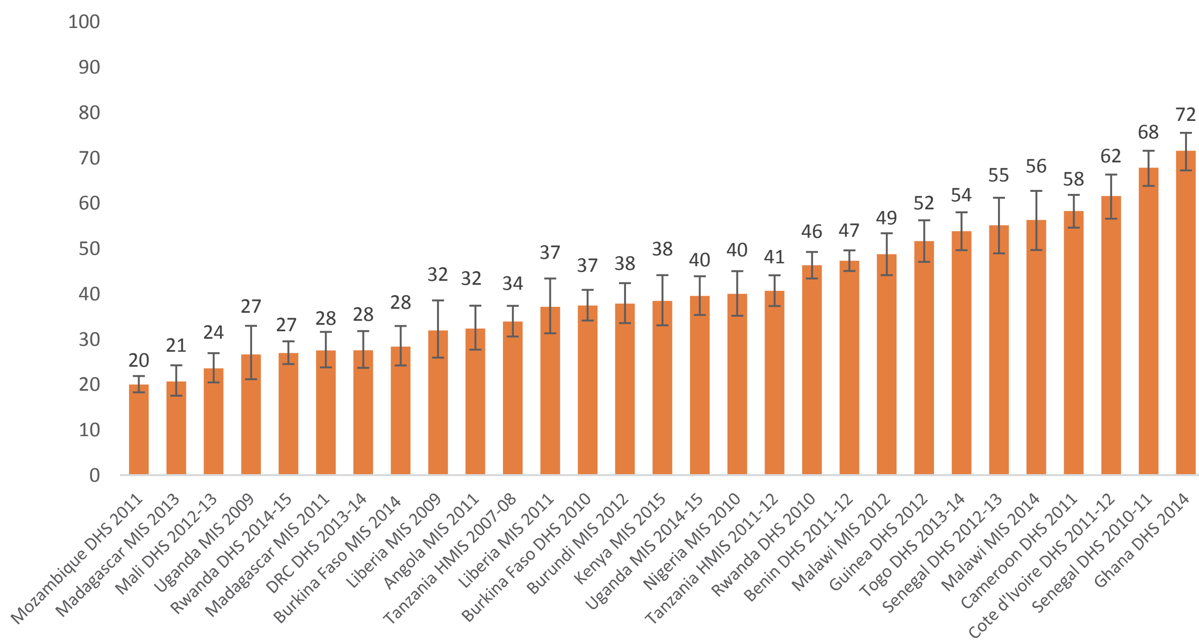
Figures 6-8 present the percentage of households with improved floor, wall, and roofing materials. The percentage of households with improved floors ranged from 12% in Burundi MIS 2012 to 93% in Ghana DHS 2014 (Figure 6). The percentage of households with improved walls ranged from 20% in Mozambique DHS 2011 to 72% in Ghana DHS 2014 (Figure 7). The percentage of households with an improved roof ranged from 21% in Madagascar MIS 2011 to 100% in Rwanda DHS 2014-15 (Figure 8). The percentage of households classified as having modern construction (improved floor, wall, and roof) ranged from 10% in Burundi MIS 2012 to 70% in Ghana DHS 2014 (Figure 9).

Figure 6. Percentage of households with improved floor, by country



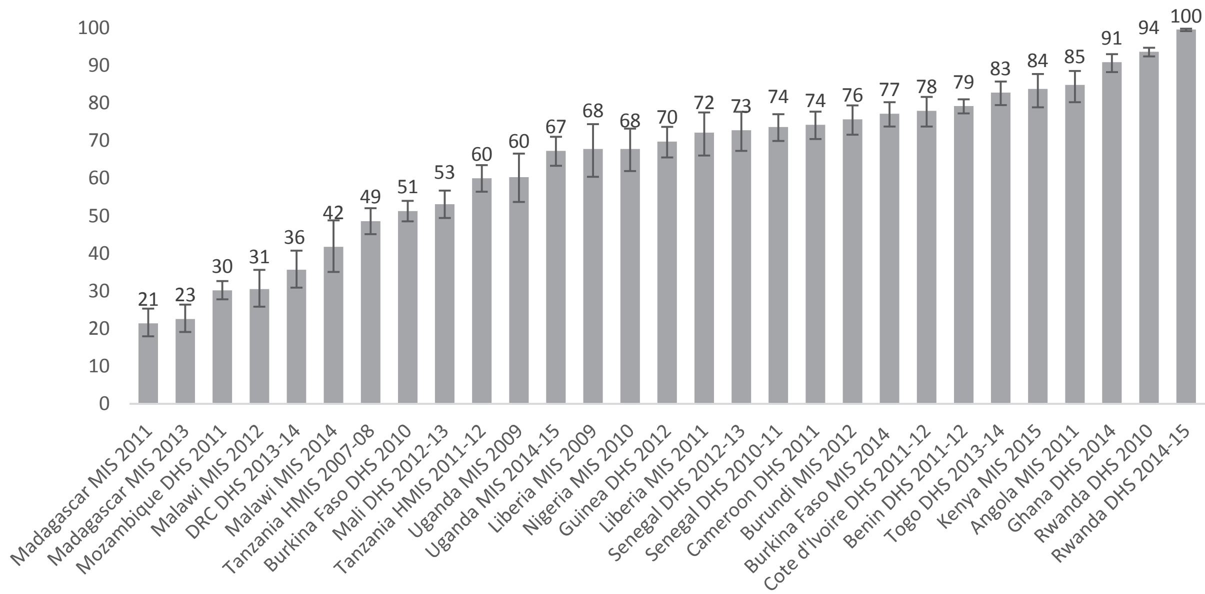
Note: Improved floor = Rudimentary and Finished materials, everything except for earth, sand, clay, mud and dung.

Figure 7. Percentage of households with improved walls, by country



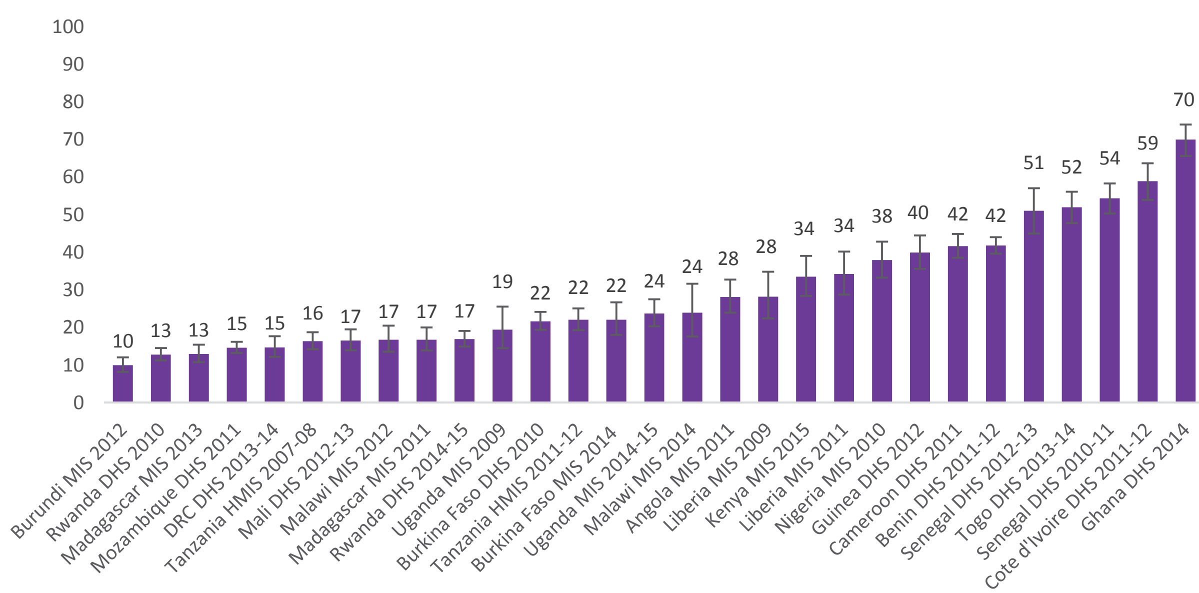
Note: Improved walls = Finished materials, such as cement, stone, bricks, and wood planks or shingles.

Figure 8. Percentage of households with improved roof, by country



Note: Improved roof = Finished materials, such as metal, wood, ceramic tiles, cement, roofing shingles and slate roofing sheets.

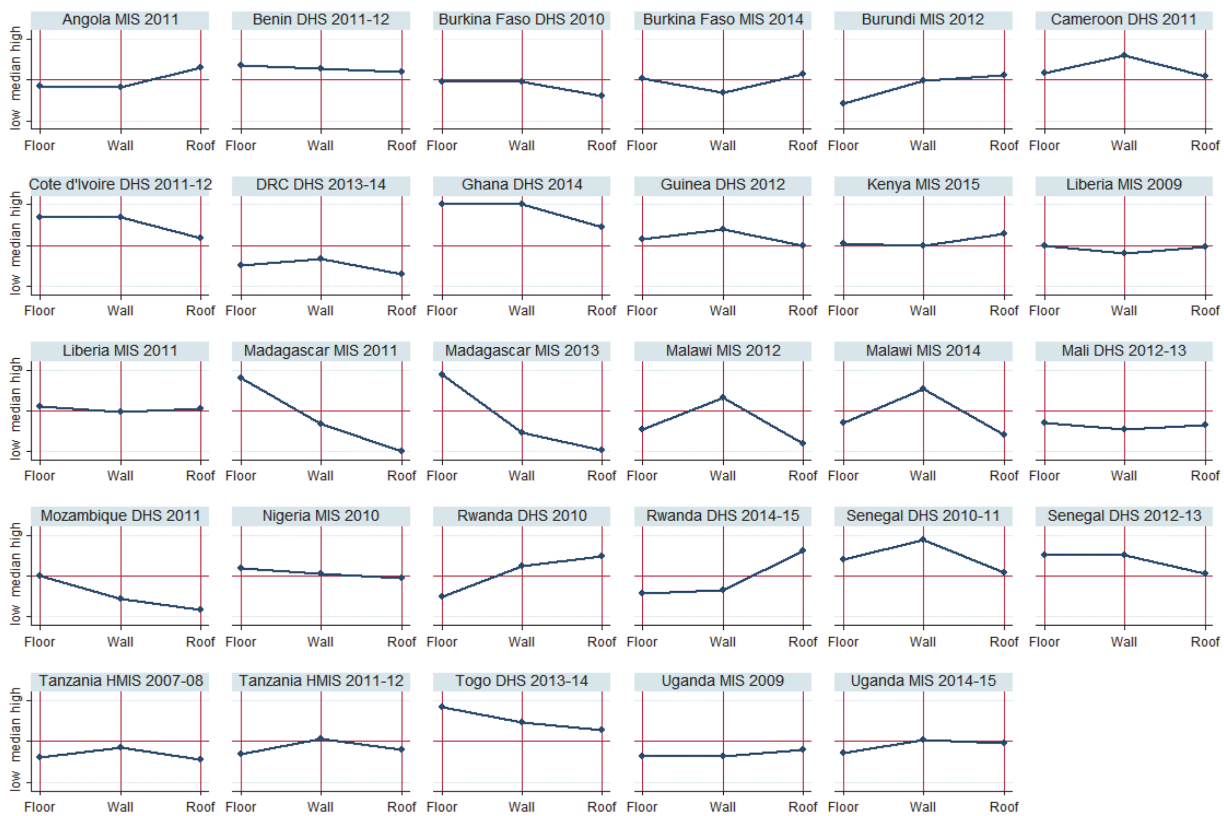
Figure 9. Percentage of households with a modern house, by country



Note: Modern house = Improved floor, improved walls and improved roof.

The pooled median percentages for the three types of improved housing characteristics were: floor (42%), wall (38%), and roof (70%). As Figure 10 shows, across the three types of housing characteristics, more countries had a higher percentage of improved roof materials than of improved wall and flooring materials. Figure 10 also shows the differences in the type of housing construction across countries comparing the country-specific values for floor, wall, and roof with the pooled median values. Some countries (Benin, Cameroon, Cote d'Ivoire, Ghana, Senegal, and Togo) have values higher than the pooled median values for all three housing variables, while other countries (DRC, Mali, Tanzania 2007-08 and Uganda 2009) have below-median values for all three housing variables.

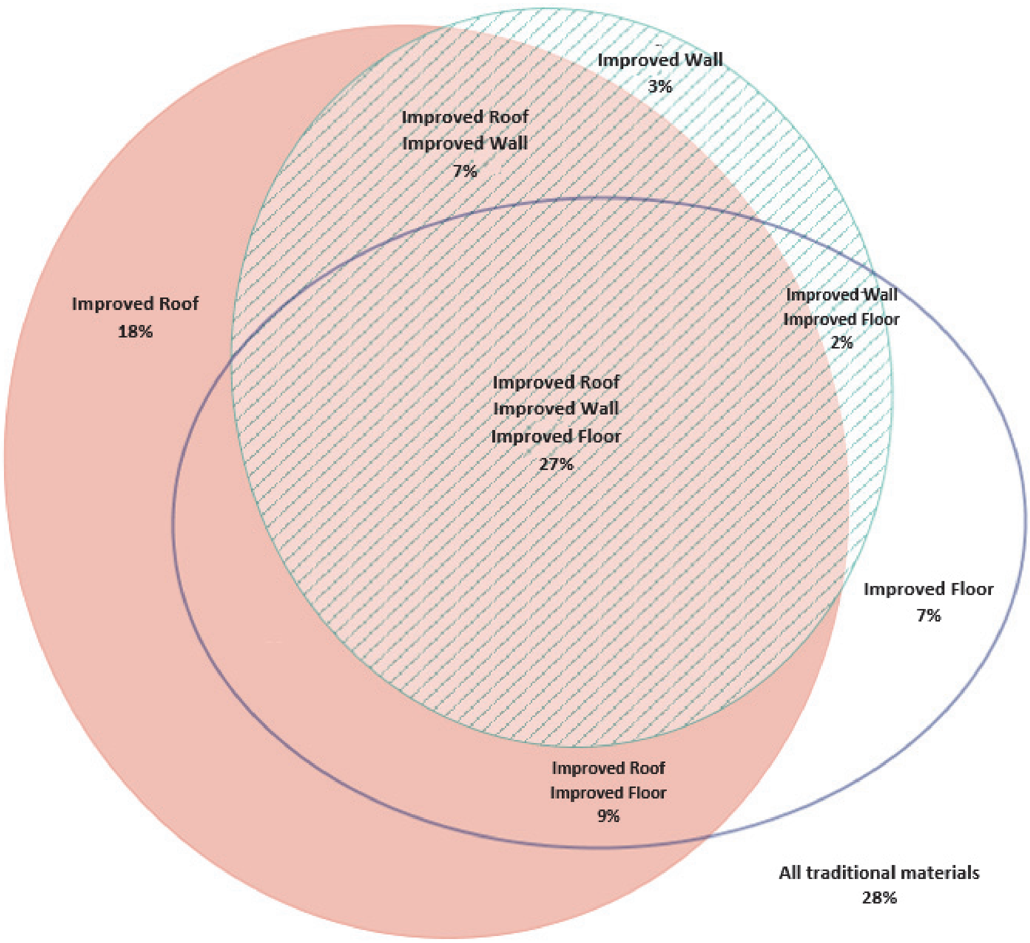
Figure 10. Parallel plot of country-specific floor, wall, and roof values compared with the pooled multi-country median values



Median Values: Floor (42%); Wall (38%); Roof (70%)

The distribution of housing characteristics in the pooled, multi-survey sample is summarized in a Venn diagram in Figure 11. Of the approximately 128,000 children age 6-59 months who stayed in interviewed households the night before surveys and who had a malaria parasitemia test result, more than a quarter (28%) lived in houses with traditional construction, defined as unimproved floor, walls, and roof. Another quarter of the study population (27%) lived in houses with modern construction, defined as improved floor, walls, and roof. Eighteen percent of children in the study lived in houses with improved roofs but unimproved walls and floor. Seven percent of the study population lived in houses with only improved floors, and 3% with only improved walls.

Figure 11. Distribution of housing characteristics in the multi-survey pooled sample



3.1.3. Housing characteristics and malaria parasitemia

Table 5 shows the prevalence of positive malaria parasitemia tests in children by the type of floor, wall, and roof construction in the child's house. In a large majority of surveys, the prevalence of positive malaria tests was higher among children living in houses with unimproved floor, wall, and roof construction compared with children living in houses with improved construction characteristics. This is the case regardless of the level of parasitemia prevalence.

Table 5. Unimproved and improved floor, wall, and roof by malaria parasitemia status for children age 6-59 months

	FLOOR				WALL				ROOF					
	Unimproved Floor		*Improved Floor*		*Unimproved Wall*		*Improved Wall*		*Unimproved Roof*		*Improved Roof*		Malaria Prevalence (%)	Number of Children
Country/Survey	%	95% CI	%	95% CI	%	95% CI	%	95% CI	%	95% CI	%	95% CI		
Angola MIS 2011	13.7	[10.0,18.5]	2.6	[1.6,4.2]	13.2	[9.6,17.9]	2.8	[1.7,4.8]	15.3	[9.2,24.3]	8.9	[6.3,12.6]	9.9	3,362
Benin DHS 2011-12	38.3	[35.2,41.5]	22.2	[20.1,24.6]	35.2	[32.5,38.0]	21.8	[19.4,24.4]	32.6	[28.8,36.6]	27.3	[25.1,29.7]	28.6	3,648
Burkina Faso DHS 2010	69.6	[67.3,71.7]	50.3	[46.9,53.7]	67.3	[65.0,69.5]	52.6	[48.5,56.7]	70.5	[68.2,72.7]	53.5	[50.3,56.7]	61.8	6,245
Burkina Faso MIS 2014	53.0	[49.5,56.5]	35.6	[31.8,39.7]	51.9	[48.6,55.1]	28.6	[24.5,33.2]	56.8	[52.3,61.1]	41.9	[38.7,45.3]	45.3	5,753
Burundi MIS 2012	18.7	[14.9,23.2]	5.8	[2.5,12.7]	23.0	[18.3,28.5]	7.9	[5.8,10.6]	25.7	[19.7,32.8]	14.6	[11.4,18.4]	17.3	3,820
Cameroon DHS 2011	34.8	[31.6,38.1]	25.4	[22.4,28.6]	35.1	[31.3,39.1]	26.2	[23.5,29.1]	36.7	[32.6,41.1]	27.6	[25.1,30.3]	30.0	5,414
DRC DHS 2013-14	23.6	[21.2,26.5]	12.4	[9.5,16.0]	24.0	[21.3,26.9]	15.9	[13.1,19.2]	25.6	[22.7,28.8]	14.8	[12.0,18.2]	21.8	7,457
Cote d'Ivoire DHS 2011-12	27.2	[21.8,33.3]	14.4	[12.0,17.1]	24.2	[19.8,29.1]	12.8	[10.6,15.4]	27.8	[21.8,34.7]	14.2	[12.1,16.6]	17.2	3,255
Ghana DHS 2014	60.7	[51.4,69.2]	34.2	[30.6,37.9]	54.4	[48.7,59.9]	28.5	[25.0,32.3]	61.7	[52.4,70.2]	33.3	[29.9,36.9]	36.0	2,529
Guinea DHS 2012	54.5	[50.1,58.8]	33.1	[29.1,37.3]	54.1	[49.1,59.1]	34.0	[30.0,38.3]	51.1	[45.5,56.7]	40.7	[36.7,44.7]	43.9	3,234
Kenya MIS 2015	6.7	[4.8,9.2]	2.8	[1.7,4.5]	6.5	[4.7,8.8]	2.5	[1.4,4.5]	6.4	[3.9,10.3]	4.7	[3.6,6.1]	5.0	3,073
Liberia MIS 2009	37.6	[32.9,42.5]	23.1	[18.8,28.0]	36.6	[32.0,41.4]	21.1	[17.1,25.7]	35.6	[30.8,40.6]	29.8	[24.7,35.5]	31.7	4,260
Liberia MIS 2011	33.8	[29.9,38]	18.3	[14.9,22.4]	32.8	[29.0,36.8]	15.6	[12.0,20.1]	33.1	[28.5,38]	23.9	[20.3,28.0]	26.5	2,941
Madagascar MIS 2011	2.9	[1.6,5.2]	7.0	[5.4,9.2]	8.3	[6.3,10.7]	1.1	[0.6,2.0]	7.5	[5.7,9.8]	1.8	[0.9,3.6]	6.3	6,212
Madagascar MIS 2013	8.6	[4.8,15.0]	9.1	[7.0,11.8]	10.3	[7.8,13.5]	4.1	[2.7,6.4]	10.3	[7.8,13.5]	4.8	[2.4,9.4]	9.0	5,564
Malawi MIS 2012	31.1	[26.4,36.3]	11.9	[8.2,17.1]	31.6	[26.4,37.4]	23.1	[18.9,27.9]	33.0	[27.9,38.5]	14.8	[11.3,19.1]	27.5	2,186
Malawi MIS 2014	38.6	[31.1,46.8]	16.2	[10.2,24.9]	39.7	[31.7,48.2]	27.6	[20.4,36.3]	40.2	[32.0,49.0]	22.7	[15.9,31.3]	32.9	2,041
Mali DHS 2012-13	58.9	[55.8,61.9]	31.2	[27.1,35.7]	59.4	[56.3,62.5]	24.8	[21.1,28.9]	64.0	[60.4,67.4]	40.2	[36.4,44.1]	51.6	4,699
Nigeria MIS 2010	46.5	[40.5,52.6]	37.8	[32.7,43.1]	47.2	[41.9,52.7]	33.8	[29.1,39.0]	50.9	[43.9,57.9]	37.5	[33.5,41.7]	41.8	5,227
Mozambique DHS 2011	42.2	[38.2,46.2]	25.2	[22.0,28.8]	39.8	[36.3,43.4]	15.8	[12.5,19.9]	44.4	[40.6,48.2]	13.6	[11.3,16.3]	35.1	4,863
Rwanda DHS 2010	1.5	[1.0,2.1]	0.8	[0.3,2.1]	1.8	[1.2,2.7]	0.9	[0.5,1.4]	2.6	[1.2,5.3]	1.3	[0.9,1.8]	1.4	4,046
Rwanda DHS 2014-15	2.6	[2.0,3.5]	0.6	[0.2,1.8]	2.9	[2.2,3.8]	0.5	[0.2,1.4]	0.0	[0.0,0.0]	2.2	[1.7,3]	2.2	3,534
Senegal DHS 2010-11	4.0	[2.7,5.9]	2.0	[1.3,3.2]	3.9	[2.5,6.1]	2.2	[1.5,3.3]	5.3	[3.6,7.8]	1.8	[1.2,2.9]	2.8	3,717
Senegal DHS 2012-13	6.6	[4.6,9.5]	1.1	[0.7,1.7]	5.1	[3.6,7.2]	1.0	[0.6,1.5]	7.0	[4.7,10.3]	1.2	[0.8,1.9]	2.8	5,407
Tanzania HMIS 2007-08	20.3	[17.9,22.9]	6.4	[4.7,8.7]	21.6	[18.9,24.6]	9.1	[7.2,11.4]	21.5	[18.9,24.3]	13.0	[10.4,16.0]	17.4	6,276
Tanzania HMIS 2011-12	4.8	[3.9,5.9]	1.8	[1.2,2.6]	5.0	[4.0,6.3]	2.5	[1.8,3.4]	5.8	[4.5,7.6]	2.8	[2.2,3.5]	4.0	7,340
Togo DHS 2013-14	48.8	[43.0,54.6]	34.3	[31.2,37.7]	49.1	[45,53.2]	25.3	[22.4,28.5]	49.8	[43.7,55.9]	33.5	[30.2,37.0]	36.4	2,994
Uganda MIS 2009	50.6	[45.4,55.8]	25.1	[20.4,30.4]	48.9	[43.9,54]	33.0	[24.4,42.9]	57.9	[53.2,62.3]	35.9	[29.7,42.7]	44.7	3,532
Uganda MIS 2014-15	24.5	[21.2,28.1]	8.5	[6.2,11.5]	22.3	[18.9,26.1]	17.0	[13.5,21.3]	29.0	[25.0,33.4]	15.9	[12.7,19.7]	20.2	4,419

CI = Confidence interval

Table 6 shows the prevalence of positive malaria parasitemia tests in children by type of housing. The prevalence of positive malaria tests was higher among children living in houses classified as having traditional construction characteristics (unimproved floor, wall, and roof) than among children living in modern houses (improved floor, wall, and roof types). This is the case regardless of the level of parasitemia prevalence.

Table 6. Traditional and modern housing type by malaria parasitemia for children age 6-59 months

	Traditional House		Modern House		Overall Malaria Prevalence	
Country/Survey	%	95% CI	%	95% CI	(%)	Number
Angola MIS 2011	12.8	[9.3,17.3]	2.4	[1.4,3.9]	9.9	3,362
Benin DHS 2011-12	34.4	[31.9,37.1]	20.9	[18.4,23.7]	28.6	3,648
Burkina Faso DHS 2010	67.7	[65.6,69.8]	40.3	[36.0,44.7]	61.8	6,245
Burkina Faso MIS 2014	51.1	[47.9,54.2]	24.6	[20.5,29.2]	45.3	5,753
Burundi MIS 2012	18.8	[15.0,23.2]	3.5	[1.6,7.5]	17.3	3,820
Cameroon DHS 2011	34.4	[31.3,37.6]	23.7	[20.5,27.2]	30.0	5,414
DRC DHS 2013-14	23.5	[20.9,26.3]	11.6	[8.6,15.5]	21.8	7,457
Cote d'Ivoire DHS 2011-12	24.8	[20.5,29.7]	11.9	[9.8,14.3]	17.2	3,255
Ghana DHS 2014	54.4	[48.8,59.9]	27.9	[24.4,31.7]	36.0	2,529
Guinea DHS 2012	52.2	[47.6,56.7]	31.0	[26.5,35.9]	43.9	3,234
Kenya MIS 2015	6.2	[4.5,8.3]	2.5	[1.3,4.8]	5.0	3,073
Liberia MIS 2009	36.4	[31.9,41.1]	19.6	[15.6,24.2]	31.7	4,260
Liberia MIS 2011	32.4	[28.8,36.3]	14.9	[11.4,19.1]	26.5	2,941
Madagascar MIS 2011	7.4	[5.6,9.7]	0.8	[0.3,1.8]	6.3	6,212
Madagascar MIS 2013	9.9	[7.5,12.9]	3.3	[1.7,6.6]	9.0	5,564
Malawi MIS 2012	30.6	[26.1,35.6]	11.7	[7.6,17.6]	27.5	2,186
Malawi MIS 2014	37.7	[30.4,45.7]	17.1	[10.7,26.3]	32.9	2,041
Mali DHS 2012-13	57.7	[54.7,60.7]	18.5	[14.6,23.0]	51.6	4,699
Mozambique DHS 2011	47.1	[41.9,52.5]	33.2	[28.4,38.4]	41.8	5,227
Nigeria MIS 2010	39.7	[36.2,43.3]	7.9	[5.8,10.5]	35.1	4,863
Rwanda DHS 2010	1.4	[1.0,2.0]	0.9	[0.4,2.5]	1.4	4,046
Rwanda DHS 2014-15	2.6	[2.0,3.4]	0.5	[0.1,2.0]	2.2	3,534
Senegal DHS 2010-11	3.7	[2.6,5.3]	2.0	[1.2,3.3]	2.8	3,717
Senegal DHS 2012-13	4.8	[3.4,6.7]	0.9	[0.6,1.4]	2.8	5,407
Tanzania HMIS 2007-08	19.8	[17.5,22.3]	4.5	[3.1,6.3]	17.4	6,276
Tanzania HMIS 2011-12	4.6	[3.8,5.6]	1.8	[1.2,2.9]	4.0	7,340
Togo DHS 2013-14	48.9	[44.9,53.0]	24.6	[21.6,27.8]	36.4	2,994
Uganda MIS 2009	49.5	[44.5,54.5]	24.5	[19.3,30.5]	44.7	3,532
Uganda MIS 2014-15	23.8	[20.5,27.4]	8.6	[6.3,11.6]	20.2	4,419

CI = Confidence interval

3.2. Multivariable Analyses

3.2.1. Improved floor

Table 7 shows the unadjusted and adjusted logistic regression models of malaria parasitemia and improved flooring. In the unadjusted models significant protective effects of improved floor were seen in all countries except Rwanda 2010 (p-value=0.25) and Madagascar. In the Madagascar MIS 2013, improved floors were associated with significantly higher odds of malaria parasitemia (OR=2.5; 95% CI = 1.5-4.2), but the association was not significant in the Madagascar MIS 2011. The adjusted models show a significant protective effect of an improved floor in Benin 2011-12 and Senegal 2012-13, (p-value<0.05) and a marginally significant protective effect in Uganda 2014-15 (p-value<0.10). Improved floors were associated with higher odds of malaria parasitemia in Madagascar 2011 (OR = 1.85; 95% CI = 1.2-2.9) and Nigeria 2010 (OR = 1.46; 95% CI = 1.0-2.1). The results of the meta-analysis (Figure 12) do not show a significant association between improved flooring and malaria parasitemia (OR = 0.96; 95% CI = 0.87-1.06). An I^2 test of heterogeneity suggests that the model represents moderate heterogeneity (I^2=39%, p-value <0.05) after adjusting for random effects at the survey level.

Table 7. Unadjusted and adjusted associations between malaria parasitemia for children age 6-59 months and improved floor (odds ratios)

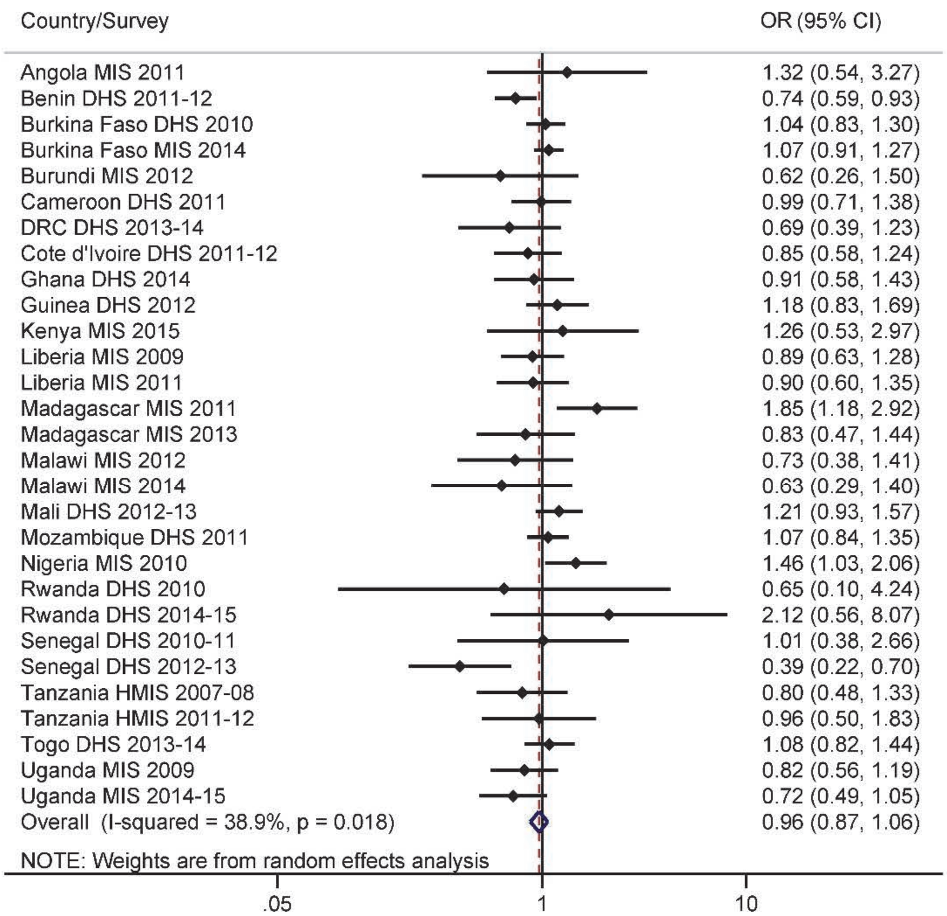
	Unadjusted			Adjusted			
Country/Survey	**OR**	**95% CI**	**p-value**	**OR**	**95% CI**	**p-value**	**Number**
Angola MIS 2011	0.17	[0.1,0.3]	<0.005	1.32	[0.5,3.3]	0.54	3,362
Benin DHS 2011-12	0.46	[0.4,0.6]	<0.005	**0.74**	**[0.6,0.9]**	**0.01**	3,648
Burkina Faso DHS 2010	0.44	[0.4,0.5]	<0.005	1.04	[0.8,1.3]	0.73	6,245
Burkina Faso MIS 2014	0.49	[0.4,0.6]	<0.005	1.07	[0.9,1.3]	0.40	5,753
Burundi MIS 2012	0.26	[0.1,0.7]	<0.005	0.62	[0.3,1.5]	0.29	3,820
Cameroon DHS 2011	0.64	[0.5,0.8]	<0.005	0.99	[0.7,1.4]	0.94	5,414
DRC DHS 2013-14	0.46	[0.3,0.6]	<0.005	0.69	[0.4,1.2]	0.21	7,457
Cote d'Ivoire DHS 2011-12	0.45	[0.3,0.6]	<0.005	0.85	[0.6,1.2]	0.40	3,255
Ghana DHS 2014	0.34	[0.2,0.5]	<0.005	0.91	[0.6,1.4]	0.68	2,529
Guinea DHS 2012	0.41	[0.3,0.5]	<0.005	1.18	[0.8,1.7]	0.35	3,234
Kenya MIS 2015	0.40	[0.2,0.7]	<0.005	1.26	[0.5,3.0]	0.60	3,073
Liberia MIS 2009	0.50	[0.4,0.7]	<0.005	0.89	[0.6,1.3]	0.54	4,260
Liberia MIS 2011	0.44	[0.3,0.6]	<0.005	0.90	[0.6,1.4]	0.61	2,941
Madagascar MIS 2011	2.52	[1.5,4.2]	<0.005	**1.85**	**[1.2,2.9]**	**0.01**	6,212
Madagascar MIS 2013	1.06	[0.6,1.9]	0.84	0.83	[0.5,1.4]	0.50	5,564
Malawi MIS 2012	0.30	[0.2,0.5]	<0.005	0.73	[0.4,1.4]	0.35	2,186
Malawi MIS 2014	0.31	[0.2,0.5]	<0.005	0.63	[0.3,1.4]	0.25	2,041
Mali DHS 2012-13	0.32	[0.3,0.4]	<0.005	1.21	[0.9,1.6]	0.16	4,699
Mozambique DHS 2011	0.46	[0.4,0.6]	<0.005	1.07	[0.8,1.3]	0.59	5,227
Nigeria MIS 2010	0.70	[0.5,1.0]	0.02	**1.46**	**[1.0,2.1]**	**0.03**	4,863
Rwanda DHS 2010	0.53	[0.2,1.5]	0.25	0.65	[0.1,4.2]	0.65	4,046
Rwanda DHS 2014-15	0.24	[0.1,0.7]	0.01	2.12	[0.6,8.1]	0.27	3,534
Senegal DHS 2010-11	0.50	[0.3,0.9]	0.02	1.01	[0.4,2.7]	0.98	3,717
Senegal DHS 2012-13	0.16	[0.1,0.3]	<0.005	**0.39**	**[0.2,0.7]**	**<0.005**	5,407
Tanzania HMIS 2007-08	0.27	[0.2,0.4]	<0.005	0.80	[0.5,1.3]	0.38	6,276
Tanzania HMIS 2011-12	0.36	[0.2,0.6]	<0.005	0.96	[0.5,1.8]	0.91	7,340
Togo DHS 2013-14	0.55	[0.4,0.7]	<0.005	1.08	[0.8,1.4]	0.58	2,994
Uganda MIS 2009	0.33	[0.2,0.4]	<0.005	0.82	[0.6,1.2]	0.29	3,532
Uganda MIS 2014-15	0.29	[0.2,0.4]	<0.005	0.72	[0.5,1.1]	0.09	4,419

OR = Odds ratio; CI = Confidence interval

Adjusted ORs with a p-value less than 0.05 are bolded

*Adjusted models control for improved walls, improved roofing, insecticide-treated net (ITN) use, indoor residual spraying (IRS) in the past 12 months, household wealth status, age of child, sex of child, and malaria endemicity

Figure 12. Pooled adjusted odds ratios of malaria parasitemia and improved floor



3.2.2. Improved wall

Table 8 presents results of unadjusted and adjusted logistic regression models of malaria parasitemia and improved walls. In the unadjusted models significant protective effects of improved walls were seen in all countries (p-value<0.05) except Senegal 2010-11, where there is a marginally significant protective effect. The adjusted models show a significant protective effect of improved walls in Burundi 2012, Madagascar 2011, Tanzania 2007-08, and Togo 2013-14 (p-value<0.05) and a marginally significant protective effect in Rwanda 2014-15 (p-value<0.10). Improved walls were associated with higher odds of malaria parasitemia in Senegal 2010-11 and Uganda 2014-15 (p-value<0.05). The multi-country pooled model (Figure 13) does not show a significant association between improved wall construction and malaria parasitemia in young children (OR = 0.96; 95% CI = 0.85-1.07). An I^2 test of heterogeneity suggests that the model may represent substantial heterogeneity (I^2=63%, p-value <0.001), even after adjusting for random effects at the survey level.

Table 8. Unadjusted and adjusted associations between malaria parasitemia for children age 6-59 months and improved wall (odds ratios)

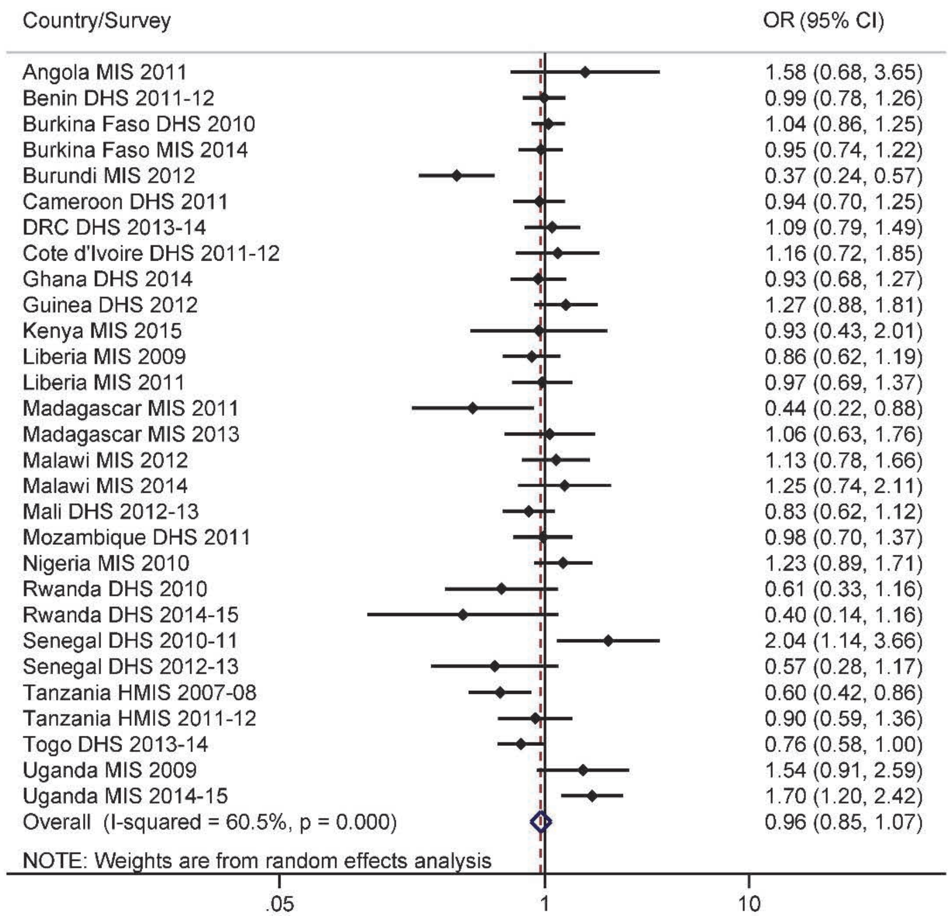
	Unadjusted			Adjusted			
Country/Survey	**OR**	**95% CI**	**p-value**	**OR**	**95% CI**	**p-value**	**Number**
Angola MIS 2011	0.19	[0.1,0.3]	<0.005	1.58	[0.7,3.7]	0.29	3,362
Benin DHS 2011-12	0.51	[0.4,0.6]	<0.005	0.99	[0.8,1.3]	0.93	3,648
Burkina Faso DHS 2010	0.54	[0.4,0.7]	<0.005	1.04	[0.9,1.3]	0.67	6,245
Burkina Faso MIS 2014	0.37	[0.3,0.5]	<0.005	0.95	[0.7,1.2]	0.71	5,753
Burundi MIS 2012	0.29	[0.2,0.4]	<0.005	**0.37**	**[0.2,0.6]**	**<0.005**	3,820
Cameroon DHS 2011	0.66	[0.5,0.8]	<0.005	0.94	[0.7,1.3]	0.66	5,414
DRC DHS 2013-14	0.60	[0.5,0.8]	<0.005	1.09	[0.8,1.5]	0.60	7,457
Cote d'Ivoire DHS 2011-12	0.46	[0.3,0.6]	<0.005	1.16	[0.7,1.9]	0.54	3,255
Ghana DHS 2014	0.33	[0.3,0.4]	<0.005	0.93	[0.7,1.3]	0.63	2,529
Guinea DHS 2012	0.44	[0.3,0.6]	<0.005	1.27	[0.9,1.8]	0.20	3,234
Kenya MIS 2015	0.37	[0.2,0.8]	0.01	0.93	[0.4,2.0]	0.86	3,073
Liberia MIS 2009	0.46	[0.3,0.6]	<0.005	0.86	[0.6,1.2]	0.36	4,260
Liberia MIS 2011	0.38	[0.3,0.5]	<0.005	0.97	[0.7,1.4]	0.87	2,941
Madagascar MIS 2011	0.12	[0.1,0.2]	<0.005	**0.44**	**[0.2,0.9]**	**0.02**	6,212
Madagascar MIS 2013	0.38	[0.2,0.6]	<0.005	1.06	[0.6,1.8]	0.83	5,564
Malawi MIS 2012	0.65	[0.5,0.9]	<0.005	1.13	[0.8,1.7]	0.52	2,186
Malawi MIS 2014	0.58	[0.4,0.8]	0.01	1.25	[0.7,2.1]	0.40	2,041
Mali DHS 2012-13	0.23	[0.2,0.3]	<0.005	0.83	[0.6,1.1]	0.22	4,699
Mozambique DHS 2011	0.28	[0.2,0.4]	<0.005	0.98	[0.7,1.4]	0.90	5,227
Nigeria MIS 2010	0.57	[0.4,0.8]	<0.005	1.23	[0.9,1.7]	0.22	4,863
Rwanda DHS 2010	0.47	[0.2,0.9]	0.03	0.61	[0.3,1.2]	0.13	4,046
Rwanda DHS 2014-15	0.18	[0.1,0.5]	<0.005	0.40	[0.1,1.2]	0.09	3,534
Senegal DHS 2010-11	0.55	[0.3,1.0]	0.05	**2.04**	**[1.1,3.7]**	**0.02**	3,717
Senegal DHS 2012-13	0.18	[0.1,0.3]	<0.005	0.57	[0.3,1.2]	0.12	5,407
Tanzania HMIS 2007-08	0.36	[0.3,0.5]	<0.005	**0.60**	**[0.4,0.9]**	**0.01**	6,276
Tanzania HMIS 2011-12	0.48	[0.3,0.7]	<0.005	0.90	[0.6,1.4]	0.61	7,340
Togo DHS 2013-14	0.35	[0.3,0.4]	<0.005	**0.76**	**[0.6,1.0]**	**0.05**	2,994
Uganda MIS 2009	0.51	[0.3,0.8]	<0.005	1.54	[0.9,2.6]	0.10	3,532
Uganda MIS 2014-15	0.72	[0.5,1.0]	0.02	**1.70**	**[1.2,2.4]**	**<0.005**	4,419

OR = Odds ratio

Adjusted ORs with a p-value less than 0.05 are bolded

*Adjusted models control for improved flooring, improved roofing, insecticide-treated net (ITN) use, indoor residual spraying (IRS) in the past 12 months, household wealth status, age of child, sex of child, and malaria endemicity

Figure 13. Pooled adjusted odds ratios of malaria parasitemia and improved wall



3.2.2. Improved roof

Table 9 presents results of unadjusted and adjusted logistic regression models of malaria parasitemia and improved roof construction. In the unadjusted models significant protective effects of improved roofs were seen in all countries (p-value<0.05) except Angola 2011, Kenya 2015, Liberia 2009, and Rwanda 2010. The adjusted models show a significant protective effect of an improved roof in Mali 2012-13, Nigeria 2010, Senegal 2010-11, and Tanzania 2011-12 (p-value<0.05) and a marginally significant protective effect in Burundi 2012, Cameroon 2011, DRC 2013-14, Malawi 2012 and Uganda 2014-15 (p-value<0.10). Improved roofing was associated with higher odds of malaria parasitemia in Guinea 2012 (p-value<0.05). The pooled estimate from the meta-analysis (Figure 14) shows a significant negative association between improved roof construction and odds of malaria parasitemia in young children (OR = 0.90; 95% CI = 0.81-0.99). However, an I^2 test of heterogeneity suggests that moderate heterogeneity between surveys may affect the pooled estimate (I^2=50%, p-value <0.05), even after adjusting for random effects at the survey level.

Table 9. Unadjusted and adjusted associations between malaria parasitemia for children age 6-59 months and improved roof (odds ratios)

	Unadjusted			Adjusted			
Country/Survey	**OR**	**95% CI**	**p-value**	**OR**	**95% CI**	**p-value**	**Number**
Angola MIS 2011	0.54	[0.3,1.0]	0.06	1.11	[0.6,2.1]	0.76	3,362
Benin DHS 2011-12	0.78	[0.6,1.0]	0.02	1.18	[0.9,1.5]	0.14	3,648
Burkina Faso DHS 2010	0.48	[0.4,0.6]	<0.005	1.02	[0.9,1.2]	0.83	6,245
Burkina Faso MIS 2014	0.55	[0.4,0.7]	<0.005	1.02	[0.8,1.3]	0.86	5,753
Burundi MIS 2012	0.49	[0.4,0.7]	<0.005	0.70	[0.5,1.0]	0.07	3,820
Cameroon DHS 2011	0.66	[0.5,0.8]	<0.005	0.71	[0.5,1.0]	0.07	5,414
DRC DHS 2013-14	0.51	[0.4,0.7]	<0.005	**0.67**	**[0.4,1.0]**	**0.05**	7,457
Cote d'Ivoire DHS 2011-12	0.43	[0.3,0.6]	<0.005	0.81	[0.5,1.2]	0.33	3,255
Ghana DHS 2014	0.31	[0.2,0.5]	<0.005	0.90	[0.6,1.4]	0.63	2,529
Guinea DHS 2012	0.66	[0.5,0.9]	<0.005	**1.92**	**[1.2,3.0]**	**<0.005**	3,234
Kenya MIS 2015	0.72	[0.4,1.2]	0.18	0.89	[0.5,1.4]	0.63	3,073
Liberia MIS 2009	0.77	[0.6,1.1]	0.12	1.25	[0.9,1.8]	0.20	4,260
Liberia MIS 2011	0.64	[0.5,0.9]	<0.005	1.15	[0.8,1.7]	0.45	2,941
Madagascar MIS 2011	0.23	[0.1,0.5]	<0.005	0.78	[0.3,1.8]	0.56	6,212
Madagascar MIS 2013	0.44	[0.2,0.9]	0.03	1.63	[0.6,4.1]	0.30	5,564
Malawi MIS 2012	0.35	[0.2,0.5]	<0.005	0.61	[0.4,1.0]	0.07	2,186
Malawi MIS 2014	0.44	[0.3,0.7]	<0.005	1.16	[0.6,2.1]	0.62	2,041
Mali DHS 2012-13	0.38	[0.3,0.5]	<0.005	**0.79**	**[0.6,1.0]**	**0.03**	4,699
Mozambique DHS 2011	0.20	[0.2,0.3]	<0.005	0.65	[0.4,1.1]	0.11	5,227
Nigeria MIS 2010	0.58	[0.4,0.8]	<0.005	**0.73**	**[0.6,1.0]**	**0.03**	4,863
Rwanda DHS 2010	0.49	[0.2,1.1]	0.08	0.92	[0.3,2.5]	0.87	4,046
Senegal DHS 2010-11	0.33	[0.2,0.6]	<0.005	**0.54**	**[0.3,0.9]**	**0.02**	3,717
Senegal DHS 2012-13	0.17	[0.1,0.3]	<0.005	0.57	[0.3,1.2]	0.14	5,407
Tanzania HMIS 2007-08	0.54	[0.4,0.7]	<0.005	1.07	[0.7,1.6]	0.74	6,276
Tanzania HMIS 2011-12	0.46	[0.3,0.7]	<0.005	**0.55**	**[0.3,0.9]**	**0.02**	7,340
Togo DHS 2013-14	0.51	[0.4,0.7]	<0.005	1.06	[0.8,1.4]	0.70	2,994
Uganda MIS 2009	0.41	[0.3,0.6]	<0.005	0.89	[0.6,1.3]	0.56	3,532
Uganda MIS 2014-15	0.46	[0.3,0.6]	<0.005	0.75	[0.5,1.0]	0.09	4,419

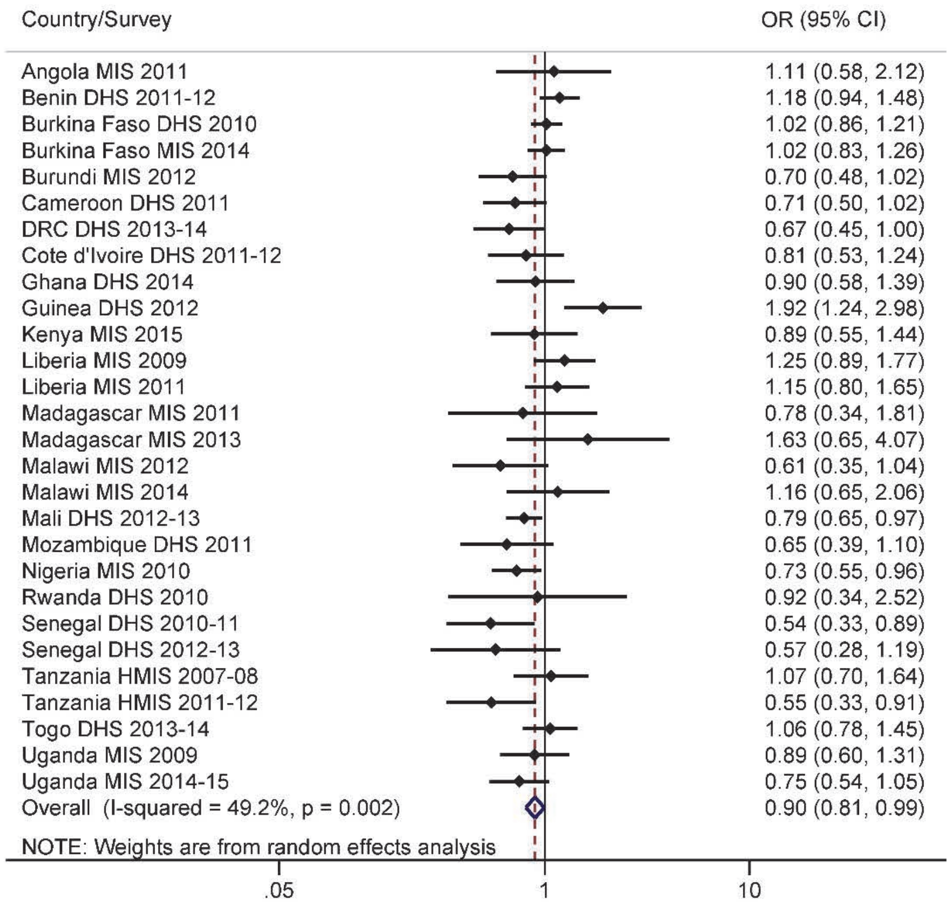
OR = Odds ratio

Adjusted ORs with a p-value less than 0.05 are bolded

+ Rwanda DHS 2014-15 was not included due to lack of variation in roofing types

*Adjusted models control for improved flooring, improved wall, insecticide-treated net (ITN) use, indoor residual spraying (IRS) in the past 12 months, household wealth status, age of child, sex of child, and malaria endemicity

Figure 14. Pooled adjusted odds ratios of malaria parasitemia and improved roof



3.2.3. Modern house

Table 10 presents the associations between modern house construction and malaria parasitemia from unadjusted and adjusted logistic regression models. In the unadjusted models significant protective effects of modern housing (p-value<0.05) were seen in all surveys except Rwanda 2010. The adjusted models show a significant protective effect of modern housing in Burundi 2012, Madagascar 2011, Mali 2012-13, Tanzania 2007-08 and Togo 2013-14 (p-value<0.05) and a marginally significant protective effect in Mozambique 2011 DHS and Senegal 2012-13 DHS (p-value<0.10). Modern housing was associated with higher odds of malaria parasitemia in Guinea 2012 (p-value<0.05) and Nigeria 2010 MIS (p<0.10). The pooled estimate from the meta-analysis (Figure 15) shows a significant protective effect of modern housing on odds of malaria parasitemia in young children (OR = 0.88; 95% CI = 0.78-1.00). However, an I^2 test of heterogeneity suggests that moderate heterogeneity between surveys may affect the pooled estimate (I^2=50.8%, p-value =0.001), even after adjusting for random effects at the survey level.

Table 10. Unadjusted and adjusted associations between malaria parasitemia for children age 6-59 months and modern house (odds ratios)

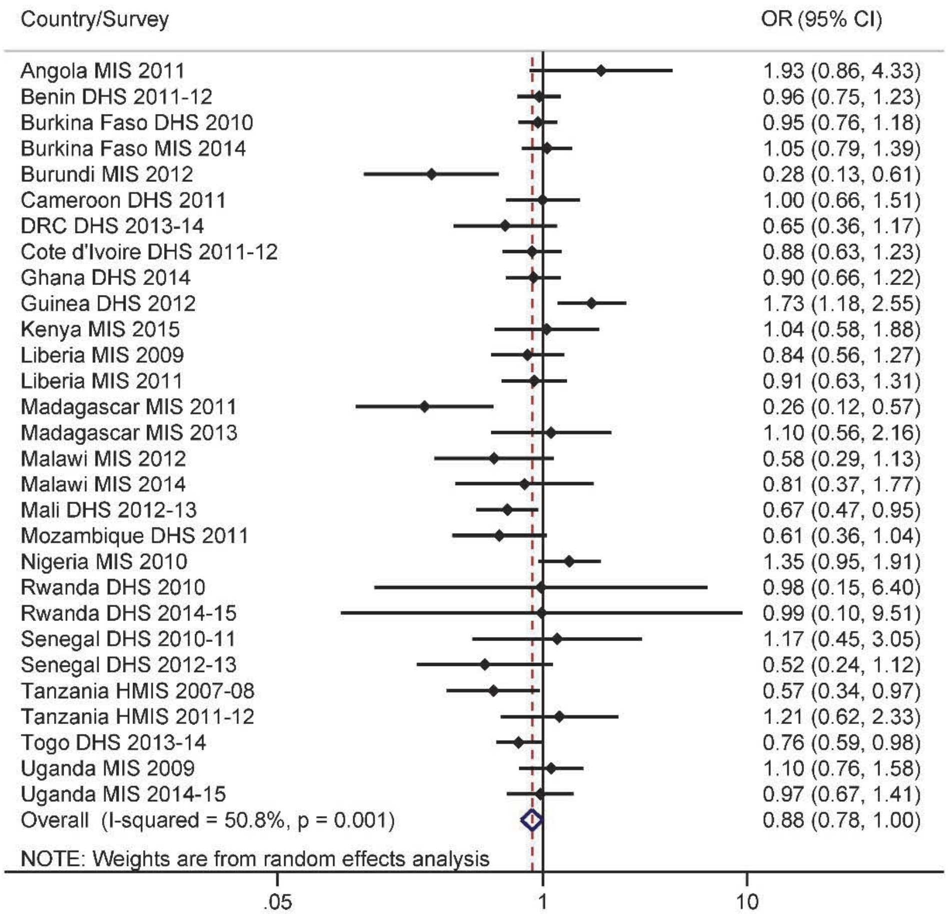
	Unadjusted			Adjusted			
Country/Survey	**OR**	**95% CI**	**p-value**	**OR**	**95% CI**	**p-value**	**Number**
Angola MIS 2011	0.16	[0.1,0.3]	<0.005	1.93	[0.9,4.3]	0.11	3,362
Benin DHS 2011-12	0.50	[0.4,0.6]	<0.005	0.96	[0.7,1.2]	0.73	3,648
Burkina Faso DHS 2010	0.32	[0.3,0.4]	<0.005	0.95	[0.8,1.2]	0.62	6,245
Burkina Faso MIS 2014	0.31	[0.2,0.4]	<0.005	1.05	[0.8,1.4]	0.74	5,753
Burundi MIS 2012	0.16	[0.1,0.4]	<0.005	**0.28**	**[0.1,0.6]**	**<0.005**	3,820
Cameroon DHS 2011	0.59	[0.5,0.7]	<0.005	1.00	[0.7,1.5]	0.99	5,414
DRC DHS 2013-14	0.43	[0.3,0.6]	<0.005	0.65	[0.4,1.2]	0.15	7,457
Cote d'Ivoire DHS 2011-12	0.41	[0.3,0.5]	<0.005	0.88	[0.6,1.2]	0.46	3,255
Ghana DHS 2014	0.32	[0.2,0.4]	<0.005	0.90	[0.7,1.2]	0.50	2,529
Guinea DHS 2012	0.41	[0.3,0.5]	<0.005	**1.73**	**[1.2,2.6]**	**0.01**	3,234
Kenya MIS 2015	0.39	[0.2,0.8]	0.02	1.04	[0.6,1.9]	0.89	3,073
Liberia MIS 2009	0.42	[0.3,0.6]	<0.005	0.84	[0.6,1.3]	0.41	4,260
Liberia MIS 2011	0.36	[0.3,0.5]	<0.005	0.91	[0.6,1.3]	0.60	2,941
Madagascar MIS 2011	0.10	[0.0,0.2]	<0.005	**0.26**	**[0.1,0.6]**	**<0.005**	6,212
Madagascar MIS 2013	0.31	[0.1,0.7]	<0.005	1.10	[0.6,2.2]	0.79	5,564
Malawi MIS 2012	0.30	[0.2,0.5]	<0.005	0.58	[0.3,1.1]	0.11	2,186
Malawi MIS 2014	0.34	[0.2,0.6]	<0.005	0.81	[0.4,1.8]	0.60	2,041
Mali DHS 2012-13	0.17	[0.1,0.2]	<0.005	**0.67**	**[0.5,1.0]**	**0.03**	4,699
Mozambique DHS 2011	0.13	[0.1,0.2]	<0.005	0.61	[0.4,1.0]	0.07	5,227
Nigeria MIS 2010	0.56	[0.4,0.7]	<0.005	1.35	[0.9,1.9]	0.10	4,863
Rwanda DHS 2010	0.66	[0.2,1.9]	0.45	0.98	[0.1,6.4]	0.98	4,046
Rwanda DHS 2014-15	0.18	[0.0,0.7]	0.02	0.99	[0.1,9.5]	0.99	3,534
Senegal DHS 2010-11	0.52	[0.3,1.0]	0.04	1.17	[0.5,3.1]	0.74	3,717
Senegal DHS 2012-13	0.18	[0.1,0.3]	<0.005	0.52	[0.2,1.1]	0.09	5,407
Tanzania HMIS 2007-08	0.19	[0.1,0.3]	<0.005	**0.57**	**[0.3,1.0]**	**0.04**	6,276
Tanzania HMIS 2011-12	0.39	[0.2,0.6]	<0.005	1.21	[0.6,2.3]	0.58	7,340
Togo DHS 2013-14	0.34	[0.3,0.4]	<0.005	**0.76**	**[0.6,1.0]**	**0.03**	2,994
Uganda MIS 2009	0.33	[0.2,0.5]	<0.005	1.10	[0.8,1.6]	0.61	3,532
Uganda MIS 2014-15	0.30	[0.2,0.4]	<0.005	0.97	[0.7,1.4]	0.88	4,419

OR = Odds ratio

Adjusted ORs with a p-value less than 0.05 are bolded

*Adjusted models control for modern house, insecticide-treated net (ITN) use, indoor residual spraying (IRS) in the past 12 months, household wealth status, age of child, sex of child, and malaria endemicity

Figure 15. Pooled adjusted odds ratios of malaria parasitemia and modern house



4. Discussion

This study used standardized data from DHS and MIS surveys to investigate associations between household construction materials and malaria infection among children age 6-59 months, controlling for additional household and child characteristics. The study covered 29 surveys in 21 countries in sub-Saharan Africa, including a range from low to high malaria transmission settings. The level of malaria control intervention coverage also varied among countries. Results of this analysis confirm small but significant protective effects of living in a house with an improved roof on the odds of malaria infection in children, but no association between type of wall and floor construction and odds of malaria infection. Children living in modern houses, defined as those with improved floors, walls and roofs, were also less likely to be infected with malaria than those living in other types of houses. Other factors associated with reduced odds of malaria in children are younger age, use of ITNs, higher household wealth, and urban residence.

Children living in houses with improved roofs were shown to have moderately lower odds of malaria infection in pooled models, and the direction of effect was consistent but not significant in all survey-specific analyses. The strongest associations between improved roofs and malaria infection were seen in Mali and Nigeria; improved roofs were associated with a 21% reduction in odds of malaria in the Mali 2012-13 DHS and a 27% reduction in the Nigeria 2010 MIS. Significant associations were also observed in the Senegal 2010-11 DHS and the Tanzania 2011-12 MIS. Marginally significant associations with improved roof construction and malaria infection were observed in five other surveys. The lack of consistently significant associations is not unexpected given the variations in malaria transmission dynamics and baseline malaria prevalence across survey settings (from 1% in Rwanda to 62% in Burkina Faso). Using household survey data to measure this association also means that a relatively small proportion of the variation in malaria risk is likely to be explained by the available covariates. An opposite effect, in which improved roof construction was significantly associated with increased odds of malaria infection in children, was seen only in the Guinea 2012 DHS. Similar results were found in a study in Kenya, in which metal roofs were associated with increased risk of malaria (Ernst et al. 2006). The authors of the Kenya study hypothesized that metal roofs were commonly found in conjunction with open eaves in the study community, which would allow for easy vector entry into houses. Also, metal roofs may have been commonly found in homes with separate kitchens instead of with kitchens in the same structure with the sleeping areas. Kitchens produce smoke which as has been shown to be a deterrent to mosquitoes in other studies (Hiscox et al. 2013). Perhaps Guinea has similar common combinations of housing features. Unfortunately, features such as open eaves or kitchen location were either not measured or were not measured consistently across the surveys. However, this association of improved roofs with increased risk of malaria appears to be an outlier and not the norm across malaria-endemic countries in sub-Saharan Africa.

Living in houses with improved walls and improved floors was not found to be associated with reductions in malaria risk in pooled models. However, disaggregated survey-specific analysis did show significant associations in some countries. Improved walls were protective against malaria infection in the Burundi 2012 MIS, Madagascar 2011 MIS, and Tanzania 2007-08 MIS but were associated with increased risk of malaria in the Senegal 2010-11 DHS. Improved floors were associated with reduced risk of malaria in the Benin 2011-12 DHS and the Senegal 2012-13 DHS, and with increased risk in the Madagascar 2011 MIS and the Nigeria 2010 MIS. The lack of consistent direction of effect and level of significance of improved housing characteristics across countries may be random and indicate that these features are not important predictors of malaria risk. However, alternative explanations are also possible. The housing-characteristic variables included in this analysis may simply be proxies for other unavailable data on housing conditions that are more directly linked to malaria transmission, such as open or closed eaves, and information on window screening. In addition, ideal housing conditions, in which the quality of construction prevents all mosquito entry into a home, and in which household residents stay within the protection offered by the house at all times of mosquito feeding, are unlikely to be common. Thus, the level of effect of housing interventions on risk of malaria infection is unlikely to be strong. Unlike many other malaria interventions, improved housing conditions do not include insecticides that directly increase vector mortality. The use of nationally representative household survey data spanning an eight-year period (2007-2015) is also likely to weaken observed associations, as these data sources contain few proximate variables and will not capture a large proportion of the variation in individual-level outcomes.

Results from models measuring the effects of modern housing suggest that the combination of improved roof, improved walls and improved floors may reduce the risk of malaria in young children. Significant, protective associations were seen in the pooled multi-survey model as well as in five of the survey-specific models. Similar to the models examining the effects of improved roofs on malaria risk, the odds of malaria infection were higher in children living in modern housing compared to other housing in only in the Guinea DHS 2012. These results would be expected if the effect of modern housing on malaria risk is being driven largely by the improved roof element of the composite measure. Reasons for the lack of a consistently significant protective effect are likely to include those previously mentioned (potential confounding by unmeasured household features such as eaves and screens, weak effects expected from cross-sectional data, a wide range of malaria transmission settings) as well as the use of a composite measure of modern housing. The distributions of the specific, individual housing features vary across countries as seen in Figure 10. The relative importance of modern housing on predicting malaria infection in any one survey may vary depending on the distribution of the individual roof, wall and floor materials in the houses that are not defined as 'modern.' The pooled, multivariable model also showed a moderate level of heterogeneity indicating significant variation between surveys.

The level of protective effect of living in a modern house on odds of malaria infection was moderate, with children living in modern houses having 12% lower odds of malaria infection than those living in non-modern houses. This compares to the recent meta-analysis by Tusting and colleagues in which odds of malaria infection were 42% lower and clinical malaria incidence was 54%-65% lower in children from modern homes compared to traditional homes (Tusting et al. 2015). Our more moderate estimate of effect is derived from a model that adjusts for the same set of core covariates in each survey, focuses on sub-Saharan Africa exclusively, and only includes surveys from 2007-2015. This is in contrast to the Tusting paper in which the mix of cohort, case-control and cross-sectional studies included in the meta-analysis ranged in date from 1939 to 2015 and came from Africa, Asia and South American countries. Traditional homes, those with unimproved roof, walls and floors, were assumed to lack closed eaves, screened doors and windows, and ceilings. In addition, the covariates included in adjusted models from individual studies varied and did not include a measure of malaria transmission levels.

In addition to housing construction, our study found that other household factors were associated with malaria infection in children. Living in urban locations was protective against malaria infection even after controlling for house construction and household wealth quintile, all of which are strongly correlated. This finding suggests that urban settings confer some protection against malaria in addition to the protection related to modern housing and greater wealth. One possible explanation is that urban environments are less conducive to dense vector populations, possessing fewer viable larval habitats. It is also possible that the greater concentration of improved housing in urban areas may confer community-level protection by reducing parasite populations. Urban residents may have greater access to health care including antimalarial treatment for infected individuals. Effective treatment of infections would reduce the parasite population in the community. It is also true that baseline malaria prevalence tends to be lower in urban than rural areas.

Malaria is not the only disease affected by improved housing construction. Other vector-borne diseases, such as dengue, chikungunya, leishmaniasis, Chagas disease, and Japanese encephalitis are influenced by housing features and by the household environment (Hiscox et al. 2013; Vector Control Working Group-Roll Back Malaria 2015; Wilson et al. 2014; World Health Organization 1997). Dirt floors put household inhabitants at higher risk of soil-transmitted helminths such as *Ascaris lumbricoides* and *Trichuris trichiura* (Quintero et al. 2012). Elements of housing construction that affect ventilation are also important; having more windows and doors is associated with fewer airborne pathogens such as tuberculosis (Escombe et al. 2007). Increased air flow may also be associated with higher levels of ITN use (von Seidlein et al. 2012). The Roll Back Malaria Vector Working Group concluded in a recent publication that "in addition to its impact on vector-borne diseases, improved housing quality brings other benefits to general health and development" and recommended modifications such as closed eaves, ceilings, and screening for reducing malaria and other vector-borne diseases (Vector Control Working Group-Roll Back Malaria 2015). Improved construction materials such as metal roofs and finished interior walls are also presented as potentially effective malaria control interventions in this report.

Improved housing is closely linked with improving socioeconomic conditions. Given the rapid development currently underway in sub-Saharan Africa (World Bank 2016), quantifying projected reductions in malaria morbidity and mortality will require a firm understanding of the protective efficacy of housing improvements, both through the direct effects on vector-human interactions and through the indirect effect of improved socioeconomic conditions. In addition to allowing for housing upgrades, improvements in socioeconomic conditions may contribute to greater access to healthcare and to other malaria control interventions. Conversely, a high malaria burden can cause declines in socioeconomic status through the costs of treatment and through lost education and income due to illness (Breman, Alilio, and Mills 2004; de Castro and Fisher 2012; Gallup and Sachs 2001). These relationships define the vicious cycle between malaria and poverty in which the poorest populations suffer disproportionate consequences of the disease.

Another advantage of improved housing construction as a malaria intervention or as an integrated vector control intervention is that can occur without requiring investment from governments or donors. Economic development is becoming more widespread in Africa, with further increases in gross domestic product expected over the next decade (World Bank 2016). An estimated 144 million new rural homes are expected to be built by 2050 (Vector Control Working Group-Roll Back Malaria 2015). These improvements should lead to reductions in malaria and other diseases even without additional donor intervention.

This study has several limitations. The data used are cross-sectional and are therefore not ideal for measuring causal relationships. However, housing conditions are unlikely to undergo major changes in the short periods of time in which a malaria infection may develop, so the lack of temporal data are unlikely to introduce much bias. Another potential limitation of the study is that the available survey data do not include information on housing characteristics other than the materials used for constructing floors, walls, and roofs. Information relevant to vector control inside a home, such as the presence or absence of open eaves and window or door screening, is not available. In addition, the study did not directly control for the seasonality of malaria transmission. The observed associations between housing conditions and parasitemia measured in this study will be affected by the underlying level of parasites and of vectors in a community. The seasonal nature of malaria transmission in many settings may lead to substantial variation in the level of risk of malaria in a population through a calendar year as well as to the nighttime behaviors of individuals (outdoor sleeping in the heat of dry seasons, for example). Although models were not adjusted for any direct measure of seasonal or weather conditions, models were adjusted for malaria transmission level using MAP risk categories, which are modeled estimates controlling for many of these environmental variables including those with seasonal variation. Given the complex epidemiology of malaria, survey data are unlikely to explain a large proportion of the variation in malaria infection observed; thus even important associations may appear weak. Pooled analyses include data from surveys conducted between 2007 and 2015. As many changes in malaria control have occurred over this period, along with substantial economic development, measures of effect between housing and malaria may have changed over this period.

At the same time, this study has several important advantages. DHS and MIS surveys are standardized to collect the same information using the same sampling and interview tools over time and across countries. This pertains to both housing characteristics and to other variable measurements such as malaria infection, age, and wealth quintile. The data are representative at the national and regional levels at a minimum, and include a wide range of malaria-endemic countries in sub-Saharan Africa, across a range of transmission intensities.

5. Conclusion

Malaria continues to cause a significant health burden in many endemic countries in sub-Saharan Africa, even after a decade of substantial investment by governments and donors, and even in settings with strong malaria control efforts. Using standardized, high-quality, nationally representative survey data, this study shows that improved house construction may be an effective malaria control intervention, as it is associated with reduced risk of malaria in young children; however the direction and strength of effect varied by household feature and by setting. More definitive conclusions will require data on housing features such as open eaves, ceilings, and window screening from DHS and MIS surveys.

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