Chapter

Low-Cost Materials for Do-It-Yourself (DIY) Installation of House Screening against *Aedes aegypti*

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Abstract

House-screening (HS) using fixed-aluminium frames to reduce the risk of indoor infestation with *Aedes aegypti* mosquitoes as well as the risk of *Aedes*-transmitted diseases in communities living in endemic areas. However, the success of this approach has been hindered by the elevated cost of the aluminium-based materials as well as their professional installation, which cannot be afforded by people living under vulnerable conditions. Cost-saving strategies such as the use of low-cost materials including wood, PVC, and Velcro are within the list of HS options available and offered by HS businesses and/or Do-it-yourself (DIY) packages *verbi gratia* ready-made and ready-to-install mosquito-screens. Here, we evaluated the efficacy of low-cost frames constructed with different materials to protect against *Ae. aegypti* indoor infestation using experimental huts. The efficacy of protection in preventing female mosquito passing inside the huts of any of the options of frames was high (>93%) compared to the control with no-screen. People's perceptions on the different materials showed the most "popular" alternative was the frame made of wood (62%). All the prototype-frames of HS made of different materials were effective at blocking *Ae. aegypti* entering-mosquitoes particularly, low-cost options like magnets and Velcro.

Keywords: house-screening, *Ae. aegypti*, low-cost materials, Zika, dengue, chikungunya

1. Introduction

"Building the vector out" and "keeping the vector out" are principles encouraged by the world health organisation (WHO) [1–3] to promote effective and sustainable housing interventions for the prevention of vector-borne diseases. Covering doors and windows with insect mesh, known as house-screening (HS), is one such intervention to "build-out" vector-borne diseases [4–7]. The WHO has historically recommended HS as a method of environmental management [8] to prevent the entry of disease-transmitting vectors into human habitations and to reduce human-vector-pathogen contact. Unfortunately, HS has been underutilised [4] and overlooked by policies & programs for the prevention and control of *Aedes*-transmitted diseases (ATDs), namely dengue, chikungunya, and Zika [9–12]. In 2017, HS was finally cited as a promising vector management approach for preventing and controlling dengue and ATDs in a research-to-policy forum convened by tropical disease research (TDR)/WHO [13–19].

HS on doors and windows, the most common entry points of mosquitoes into a house, works as a physical barrier that reduces the access and subsequent contact of humans with "hungry" female mosquitoes searching for blood within houses. We recently evaluated the efficacy of HS permanently fixed with aluminium frames to reduce *Ae. aegypti* mosquitoes and the risk of ATDs in a cluster randomised controlled trial in the Mexican city of Merida, Mexico [20–23]. Compared to unprotected households located in the control arm, houses with HS showed a lower risk (OR≈0.50) of finding indoor *Ae. aegypti* female mosquitoes. On the note, compared to those unprotected households, the presence of *Ae. aegypti* infected with dengue and Zika viruses was reduced in clusters with HS by 71%.

Although HS can be considered an effective and, more importantly, an "available" method to reduce mosquito contact with humans in the households of Merida, the cost of the house-installing of HS is high. Thus, no HS was installed prior to the intervention [22]. The current cost for the professional installation of HS by "aluminium & mosquito-screens" (A&MS) establishments in Merida with aluminium frames in an average house is ~$ 140 USD (two doors and 7 windows). Although the price per m^2 of a regular fibber-glass net used for HS is ~$ 0.85 USD, most of the cost for protecting a house with HS is due to the cost of frames and hardware (72.5% of the total cost) and hand labor (18% of the total cost) if installed by an A&MS professional.

Potential solutions to increase community access and make HS more affordable identified in a previous phase of implementation [22, 23] included introducing low-cost strategies such as the use of less-expensive materials rather than using the aluminium frames offered by A&MS companies and/or the commercialised Do-it-yourself (DIY) packages v.gr. ready-made and ready-to-instal mosquito screens with low-cost materials. Here we described some evidence of the use of inexpensive materials for the installation of HS as additional options used by households and/or small businesses in increasing HS affordability, HS efficacy and acceptance, and ultimately, HS access to the community.

2. Potential options for frame materials other than aluminium, prototype design and manufacturing

The study involved different research topics/components related to using different materials rather than aluminium to instal HS. First, our team searched, reviewed, and selected different materials to replace aluminium frames, then designed and constructed prototypes with those materials. Using Google and other shopping platforms such as Amazon, eBay, and Mercado Libre, from March to April 2019 we sought "mosquito screens", "insect screens", "window screens", and "door screens" in order to identify different potential models and materials that were different from aluminium. As the inclusion criteria, we considered availability in the market, less expensive than aluminium, and suitability for housing structures, such as the ability to keep mosquito nets fixed on doors and windows. After the online review, the team visited local suppliers to check for the availability of the materials in the local-regional-national market.

In the initial phase, we designed and built small-scale prototypes (1: 5 of a window and 1:10 of a door) and real-sized versions (average size of 2.20 × 0.95 m for doors and 1.20 × 0.80 m for windows found in houses from different neighbourhoods in Merida) (**Figure 1**). All materials required for installation including rivets, adhesives, screws, nails, fabric, locks, among others, along with some additional information such as handling, time for manufacturing per square meter, were identified, evaluated, and recorded, information later used to calculate the total costs based on the different options (**Table 1**, **Figure 1**). A regular fibber-glass net (brand Herralum®)

Figure 1.
Different options and materials for the installation of house screening other than aluminum: (1a–1d) wood, (2a–2c) polyvinyl chloride plastic (PVC), (3a–3c) velcro and (4a–4c) magnets.

Material	Materials	Costs in USD
Aluminum	28 pcs aluminum frame for windows, 5 pcs of aluminum for doors, 28 galvanized frame corners, 18 m of fiberglass net (1.50 m of width), 45m of spline #10, 15 screws round head $1^{1/2}$ × 8", 8 screws round head 1 × 8".	91.00
Wood	33 Wood strips (4 width × 1.8 thickness cm), 1 pc of glue, 18m fiberglass net, 8 wood screws, 25 staples.	43.00
PVC	33 PVC strips, 1 pc of glue, 18m fiberglass net, 6 PVC frame corners, 3 pcs silicone sealer.	39.00
Magnet	20 m of polyester cloth, 66 small magnets, 18m fiberglass net, 14 pcs of wooden rod, 3 pcs of thread? rows, 2 sewing needles	34.00
Velcro	33 velcro strips, 18m fiberglass net, 3 pcs row, 2 sewing needles	30.00

Table 1.
Costs associated with different materials that can be used for the construction of frames for house-screening. Costs for installing house-screening per house: including seven windows and two doors. Costs only consider materials and exclude cost of installation (1 USD = $23.00 MX PESOS).

with the following dimensions and features: 30 m length × 1.50 m width rolls, colour grey, mesh light 0.6 × .07 mm, density 0.32 mm was used to as blocking barrier.

To replace aluminium for HS frames, several potential options were identified as follows: wood, polyvinyl chloride plastic (PVC), Velcro, and magnets. All these materials can be installed in doors and windows and are less expensive than aluminium. In fact, magnets and Velcro were the less costly options, followed by PVC and wood. Additionally, these were available within local and national markets, and more importantly, easily accessible to the population.

Several options were identified for the installation of HS, including fixed (not mobile), retractable, and removable HS frames. Fixed insect HS screens are the most common insect screens, not mobile and held by a stable frame. Like fixed HS, retractable screens are also fixed, but they can be opened/closed with a "rolling" system. Finally, removable screens use adhesive or magnetic elements, contain a temporarily fitting system, and are usually an "easy DIY installation". All of these options are versatile and functional with an enriched market, including numerous accessories and colours that you can choose from.

3. Evaluation of prototypes in experimental huts

On March 2019, a trial following a 6 × 6 Latin-square experimental design was performed to evaluate the HS installation in experimental huts at the unidad colaborativa para bioensayos entomologicos (UCBE) in Merida using different low-cost prototype options vs. the gold standard (aluminium frames) (**Figure 2**). We quantified the entomological impact (entry or exclusion) of each of the different materials/installation as a physical barrier against female *Ae. aegypti* mosquitoes using experimental huts as testing systems. Experimental huts are simplified, standardised representations of human habitations that provide model systems to evaluate mosquito responses to different control methods [24, 25].

Mosquito screens (with regular fibber-glass net, brand Herralum®) with each of the different framing materials were made as real-sized doors (2.20 × 0.95 m) and fixed on an entrance located within the release tunnel of experimental huts (**Figure 2**).

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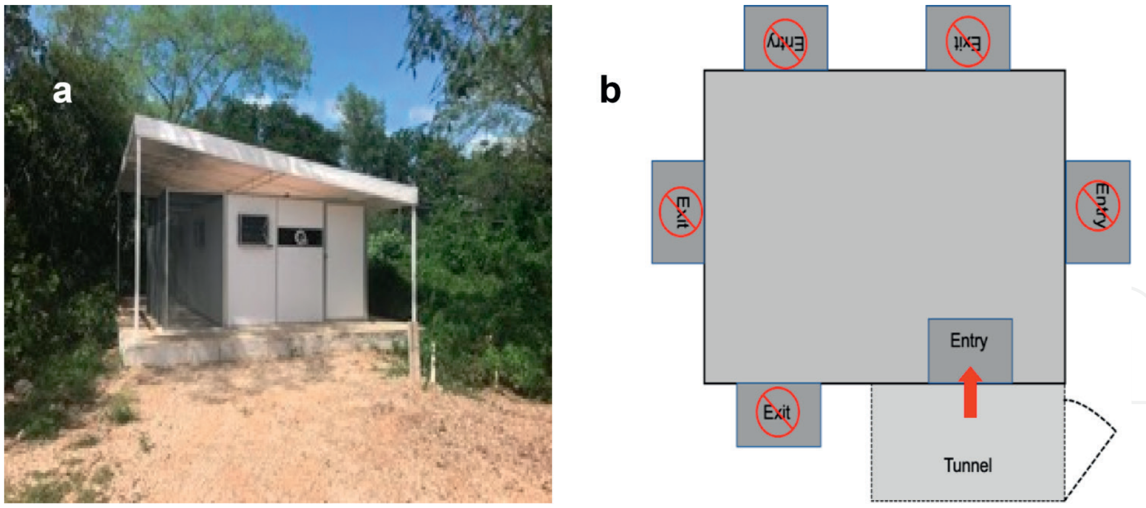

Figure 2.
(a and b) Experimental huts and (c–f) experimental layout of the different options and materials tested.

All the other entries-exits of the hut were sealed. The mosquito-door-screens of each material were fixed with its corresponding method of installation (**Figure 1**) and evaluated for a 24-hour period, and next day swapped of the hut until a total of six replicates were completed following the Latin-square experimental design. One of the huts was always left without protection as control.

Groups of 2–5 days-old and non-fed female *Ae. aegypti* mosquitoes (New Orleans F3 strain reared at UCBE) (n = 100), were released in the tunnel of the experimental huts in the morning (8:30 a.m) and collected 24 hours later. A BG-sentinel mosquito trap [26] with its bait (weight 1.7 kg, Dimension 38 × 47, ventilator 12 V dc 3.6 watt.) added with CO_2 (generation rate of 200 ml/min) [10, 27], was set inside the hut and active for collections for the whole 24-h period. In addition, the interior of the hut was revised, and any mosquito found was collected with Prokopack aspirators [10]. Mosquitoes that did not enter were collected (from the tunnel and outside the hut) with Prokopack aspirators. The collected mosquitoes were kept in a recovery bottle and then stored at −20°C for counting. Data was computed as the difference between initial mosquito abundance (adult) and the values at 24 hours post-release.

Frame material	Mean No. *Ae. aegypti* females entering after 24 h (95% C. I.)	% Protection (95% C. I.)	Incidence rate ratio (95% C. I.)	SE (mean)	P value
Aluminum	0.7 (0.4–1.7)	99.2 (97.9–100.5)	0.01 (0.003–0.02)	0.004	<0.001
Wood	1.7 (0.1–3.2)	97.9 (95.9–99.9)	0.02 (0.01–0.04)	0.01	<0.001
PVC	2 (0.7–3.3)	97.6 (96.0–99.2)	0.02 (0.01–0.04)	0.01	<0.001
Magnets	5.7 (2.6–8.7)	93.1 (89.6–96.7)	0.07 (0.05–0.10)	0.01	<0.001
Velcro	5.7 (2.6–8.8)	92.9 (88.9–97.0)	0.07 (0.05–0.10)	0.01	<0.001
Control	82.3 (77.9–86.7)	17.7	—		

Table 2.
Efficacy of protection (relative to the control treatment) against Aedes aegypti *(entry of mosquitoes) with frames constructed from different materials in the experimental huts. A total of 100 adult female* Ae. aegypti *mosquitoes were released into entry chamber in each treatment (n = 6 huts): Control, velcro, Magnet, PVC, Wood, and Aluminum.*

Table 2 presents the comparative results of the efficacy of frames constructed from different materials and their protection against *Ae. aegypti* (entry of female mosquitoes) in the experimental huts. All HS options had a high efficacy (>93%) in preventing female mosquitoes from passing inside the huts once compared with the control huts with no-screen. The aluminium-based HS showed the highest protection by blocking 99% of female mosquitos going inside the households (IRR = 0.01, C.I. 0.003–0.02); however, the low-cost options which cost is 60% lower than aluminium, also performed well as follow: magnets (Average protection = 93.1%, 95% CI = 89.6–96.7) and Velcro (Average protection = 92.9%, 95% CI = 88.9–97.0).

4. Consumer opinion and small company's perspective on HS prototypes

Here, to investigate people's perception of low-cost materials to replace aluminium frames, we applied a questionnaire (**Table 3**) to 55 families that had previously received the installation of HS with aluminium frames (July–August 2019) as part of the cohort project [22, 23]. In this survey, participants were asked about the distinct material options as if they would be hypothetically installed on their houses to replace aluminium frames. Questions included whether they have any previous knowledge or experience with the alternative materials/frames, perception of the cost of the materials, durability, aesthetics, the installation process, and their preferences (if any) for a specific type of frame. During this process, small-scale prototypes constructed were shown as well as the pictures of the real-sized prototypes installed in a house (**Figure 1**) to people, but no other explanation was given to avoid bias in answers.

A high percentage of the participants interviewed were women (76.36%, 42/55) with ages ranging between 30 and 50 years old (54/55); all of them were married and heads of families from houses that had received the HS installation previously as part of the cohort project. Frames made of wood (62%, 34/55) were the most "popular" alternative among the participants, followed by magnets (45%, 25/55), PVC (45%, 25/55), and Velcro (29%, 16/55). People acknowledged the existence of wood frames, but the other materials v.gr. PVC, Velcro, and magnets were "uncommon" to them; although some participants recalled having seen the other options on the Internet, magazines, or TV programs. Regarding the cost, 45–60% of participants believed that the prices of the four different frames were between 5 and 50 USD, and they thought Velcro and magnets were expensive. The expected durability of the materials was associated with weather conditions, but most participants thought that all materials were highly resistant (which could last 1–5 years). On the aesthetics, which is the perception of "how beautiful" the frames can be seen on the houses, the wood option got the best scores (73%, 40/55), followed by magnets (56%, 31/55). More than 50% of the interview participants thought all the options were easy to instal; however, many of them disagreed on how easy to maintain them. All materials were seen as an acceptable positive improvement of the house except for PVC.

We also investigated the perspective of A&MS businesses on the prototypes/materials (November–December 2020). To do so, A&MS companies located in Merida, Yucatan were identified (n = 100) by searching on Yellow pages. Because of COVID-19 pandemic, person-to-person contact was avoided, so telephone calls were used to reach them. Forty companies dedicated to the assemblage of HS in the city of Merida were surveyed (**Table 4**). Participants were asked about costs, durability, aesthetics,

Previous knowledge/experience with alternative materials for HS				
Responses	**Wood**	**PVC**	**Velcro**	**Magnets**
Yes	(39/55) 71%	(7/55) 13%	(5/55) 9%	(1/55) 2%
No	(16/55) 29%	(47/55) 85%	(50/55) 91%	(54/55) 98%
Do not know	0%	(1/55) 2%	0%	0%
Cost perceived				
5–50 USD	(25/55) 45%	(28/55) 51%	(33/55) 60%	(28/55) 51%
50–100 USD	(19/55) 35%	(26/55) 29%	(12/55) 22%	(12/55) 22%
Up to 100 USD	(5/55) 9%	(2/55) 4%	(1/55) 2%	(5/55) 9%
Do not know	(6/55) 11%	(9/55) 16%	(9/55) 16%	(19/55) 18%
Expectation of durability				
Less than a year	(3/55) 5%	(6/55) 11%	(11/55) 20%	(1/55) 2%
1–2 years	(22/55) 40%	(16/55) 29%	(20/55) 36%	(17/55) 31%
2–5 years	(18/55) 33%	(21/55) 38%	(22/55) 40%	(20/55) 36%
More than 5 years	12/55) 22%	(12/55) 22%	0%	(7/55) 13%
Do not know	0%	0%	(2/55) 4%	(10/55) 18%
Aesthetics				
Yes	(40/55) 73%	(15/55) 27%	(23/55) 42%	(31/55) 56%
No	(15/55) 27%	(35/55) 64%	(28/55) 51%	(21/55) 38%
Do not know	0%	(5/55) 9%	(4/55) 7%	(3/55) 5%
Easy to install				
Yes	(37/55) 67%	(29/55) 53%	(36/55) 65%	(36/55) 65%
No	(15/55) 27%	(14/55) 25%	(10/55) 18%	(9/55) 16%
Don't know	(3/55) 5%	(12/55) 22%	(9/55) 16%	(10/55) 18%
Easy maintenance				
Yes	(27/55) 49%	(21/55)38%	(29/55) 53%	(25/55) 45%
No	(23/55) 42%	(22/55) 40%	(15/55) 27%	(17/55) 31%
Do not know	(5/55) 9%	(12/55) 22%	(11/55) 20%	(13/55) 24%
Preferences and acceptance				
Yes	(34/55) 62%	(25/55) 45%	(16/55) 29%	(25/55) 45%
No	(12/55) 22%	(20/55) 36%	(28/55) 51%	(21/55) 38%
Do not know	(9/55) 16%	(10/55) 18%	(11/55) 20%	(9/55) 16%

Table 3.
Results recorded from householders about alternative frame materials other than aluminum for the installation of house-screening in Merida, Mexico.

perceived comfort, acceptance, and an open section on the customer preferences from entrepreneurs' perspectives, and the production-manufacturing process of the HS (**Table 4**). Small-scale prototypes and a photographic catalog of the different prototypes (**Figure 1**) were also employed.

	Aluminum	Wood	PCV	Velcro	Magnets
Material preferred (N = 31)	96.77% (30/31)	3.23% (1/31)	0% (0/31)	0% (0/31)	0% (0/31)
Material most requested by consumers (N = 31)	100% (30/31)	43.3% (13/31)	10% (3/31)	0% (0/31)	0% (0/31)
Perceived cost (N = 40)	Expensive (97.5%, 39/40)	Cheap (7.5%, 3/40)	Cheap (12.5%, 5/40)	Cheap (52.5%, 21/40)	Cheap (57.5%, 23/40)
Duration of materials perceived/expected (N = 40)	8.5 years	21.85 months	21.24 months	8.44 months	9.56 months
Opinion but aesthetic (N = 40)	NA	57.5% (23/40)	20% (8/40)	12.5% (5/40)	47.5% (19/40)
Easy to manufacture	NA	96% (26/27)	92% (23/25)	100% (23/23)	100% (25/25)
Easy to maintain	NA	89% (24/27)	96% (23/24)	100% (19/19)	95% (20/21)

Table 4.
Perspectives of professional small companies dedicated to the installation of house-screening about potential low-cost alternatives to replace aluminum frames.

We identified "producers", those who manufacture and instal HS, and "distributors" who only sell materials for HS. Fifty-five percent of (22/40) the companies declared to be in the formal sector and the remaining 45% (18/40) were informal. Of those in the formal sector, 59.09% (13/22) were producers, the remaining 40.90% (9/22) were distributors, and the informal ones were only producers. Only one producer (1/31) made mosquito nets with one of the alternative materials (wood).

The interviewed producers declared that the alternative material most requested by consumers after aluminium was wood (41.93% [13/31]) (**Table 4**) and that few of them had received requests for PVC (9.67% [3/31]); and recalled that customers had never requested them for Velcro or magnets. Respondents considered aluminium to be an expensive material (97.5% [39/40]); despite not working with alternative materials, some considered wood and PVC were cheaper (7.5% [3/40], 12.5% [5/40], respectively), and considered that Velcro and magnets were the less expensive options (52.5% [21/40], 57.5% [23/40]) (**Table 4**). Regarding the duration of the alternative materials, they expected an average extent of 21.9 months for wood, 21.2 months for PVC, 8.4 months for Velcro, and 9.6 months for magnets (**Table 4**). Wood and magnets (57.5% [23/40], 47.5% [19/40]) were considered the most aesthetical alternative materials for the elaboration of HS (**Table 4**). Regarding whether alternative materials are easy to manufacture and maintain, many of the interviewees could not answer because they do not know enough about the material to give a real opinion (**Table 4**). However, those who responded considered that the alternative materials were easy to manufacture and maintain.

Although alternative materials are considered cheaper, aesthetic, easy to maintain and instal by A&MS small companies, they declared not willing to use this type of materials and rejected the use of Velcro (97.5% [39/40]), PVC (90% ([36/40]), magnets (82.5% [33/40]) and wood (77.5% [31/40]). Nevertheless, they acknowledged that consumers could request these materials, with wood being the material with the highest potential to be requested (43.1%), followed by PVC and magnets (22.5%) and finally Velcro (14.4%).

5. Conclusions

In this study, we examined the efficacy of low-cost frames built using different materials (e.g. wood, PVC, Velcro) to protect against *Ae. aegypti* getting inside experimental huts. All HS frame prototypes described here were highly effective in blocking the entry of *Ae. aegypti* mosquitoes (>93%), and even without "total" protection, entry was lower compared to no netting. Of note, all the prototype frames of HS made of different materials rather than aluminium, were low-priced. For instance, HS made with magnets and Velcro performed very well against mosquitoes and had a 54–68% lower cost than aluminium. Thus, it was estimated that protecting a house (with seven windows and two doors) using these no-aluminium materials costs about US$35 [22].

Additionally, we investigated people's perceptions of using different materials to build HS. The most "popular" and more commonly used alternative was the wooden-made frame (62%) compared to magnets, Velcro, and PVC-based frames; this latter was considered the "least popular" material as it was not considered a positive improvement to the houses. To mention, aluminium is usually associated with quality and aesthetics, as well as an improvement of the home, which poses an enormous burden on using low-cost materials as these must be aesthetically accepted by the community to be perceived as an improvement in the quality of their housing and living conditions. On top of this, little or no information on the characteristics, effectiveness, cost, and availability of the different materials used to build HS rather than aluminium are available; therefore, this latter is considered the only option to build HS, limiting people's perspective on installing not-aluminium-based HS in their houses, instead leaving them unprotected.

During the interviews, people learned about these low-cost options through demonstration prototypes and expressed their doubts; expanding their options to request from A&MS or to assemble and instal themselves in their homes. Small A&MS businesses, being more accessible, provide an important service to the population, especially the low-income population. Therefore, producers and consumers need information and alternatives to evaluate. Thanks to the companies surveyed, we know that they tend to produce 30 units of aluminium mosquito nets (for one window) per month, costing on average USD 14.83 each and with an approximate profit of 40%. It will last almost 10 years and the professional service, if any, is only to change the broken/damaged ones. It would be useful to show the benefits of all the different alternatives for established producers; for example, Velcro and magnets are the materials with the highest benefits, derived mainly from the short lifetime, which increases the frequency of purchases. However, they are also easy for users to instal themselves at home.

Overall, these results support the possibility of using alternative, accessible, and less expensive materials such as wood, PVC, Velcro, and magnets, instead of aluminium-based HS to protect people's houses against *Ae. aegypti* invasion inside households. This study changes the paradigm between the A&MS seeking to maximise their profit and the consumers seeking cheaper costs. According to the A&MS, the quality and durability of aluminium are unmatched, and they do not have the "social benefit" of consumers as a policy. Low-income people are constrained by the cost of conventional house screens and the labor involved; unaware of alternative models, their households lack protection against *Ae. aegypti*. Therefore, this study suggests strategies involving the government, the private sector, and academia for disseminating and accessing these low-cost alternative materials, either through micro-credits, vouchers for people at risk (e.g., pregnant women), or partial or monthly payments.

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