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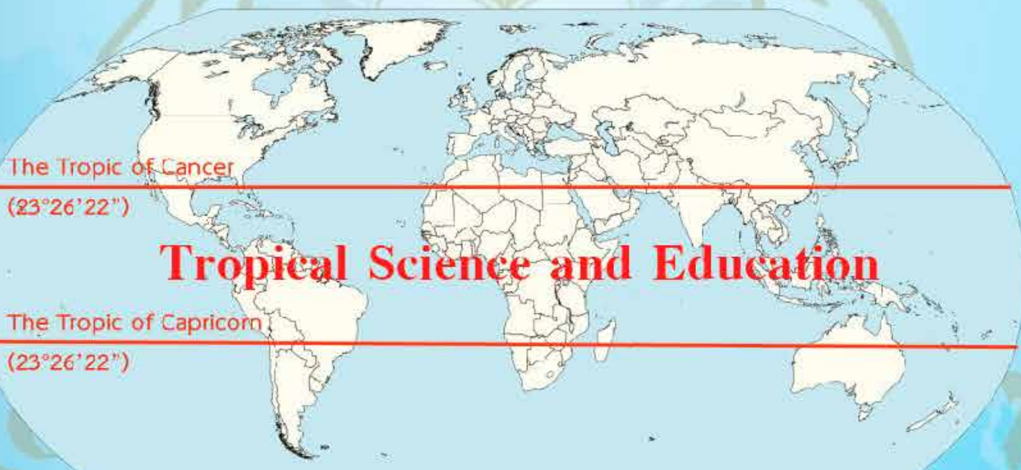

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The Thermal Performance and Acceptance of a Thai Bamboo House in Tanzania.

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Abstract

Traditional, rural homes in tropical sub-Saharan Africa are often ground floor, waddle and daub structures and differ from the Asian elevated, air-permeable houses even though the climate zones are similar. We assessed the relative comfort of living in a Thai-style bamboo house compared with a traditional African mud house in a hot and humid zone in Africa.

A team of Thai craftsmen built a bamboo house in Magoda. Tanzania. The bamboo was locally sourced. We compared the relative comfort of living in a Thai style house with a traditional African house using temperature and humidity recordings over 4 months, particularly between 19:00 to 22:00 when decisions are made where to sleep and assessed acceptability of the Thai house to local residents.

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The construction of a Thai-style bamboo house took two weeks after the construction materials were in-site. The indoor climate assessment of the house indicated that residents in the bamboo house are likely to feel comfortable 85% of the time while the residents in the mud house would only feel comfortable 34% during that time between 19:00 to 22:00. The bamboo house was well accepted by the villagers and has served as accommodation for the residents since hand-over in 2015.

The typical Thai bamboo house in Tanzania provided a substantially more comfortable indoor climate compared to the traditional African mud house. The residents were happy with the house design and continue to use the Thai bamboo house. Novel designs hold considerable promise as a sustainable approach to provide housing for the rapidly expanding population of Africa and may carry health benefits.

Keywords: malaria, vector borne diseases, mosquitoes, respiratory tract infections.

Introduction

South East Asia and much of sub-Saharan Africa share a hot-humid climate but rural housing has evolved quite differently in these areas (Knudsen & Seidlein, 2014). Traditional rural houses in South East Asia are usually elevated on stilts or columns, have air-permeable walls, have large windows and have floors usually made of wooden planks or bamboo slats (Table 1). In contrast, traditional housing in rural sub-Saharan Africa tends to be a waddle and daub constructions known as mud houses with relatively heavy, impermeable walls and few if any windows (Figure 1). The waddle and daub walls are made by interlacing sticks, which are later covered with slabs of mud.

Table 1: Major differences in construction characteristics of rural housing in South East Asia and subSaharan Africa

	Houses in South East Asia (e.g. Thailand)	**Houses in subSaharan Africa (e.g. Tanzania)**
Placement	Generally elevated off the ground by columns or stilts.	Nearly always on the ground level.
Floors	Wooden or rolled-out bamboo planks.	Compacted soil or concrete.
Walls	Cladding is made of air permeable materials such as loosely spaced bamboo or wood planks which assure ventilation.	The waddle and daub walls are typical but may be replaced with burnt brick.
Windows	Many, large windows	Few, small or absent

One of the major drawbacks of the waddle and daub structures are their short life span; they disintegrate when exposed to rain and require constant re-plastering. Thatched roofs have to be re-done every two to three years, are a continuous source of particulate matter falling indoors, may be a hiding place for snakes and other vermin and are a fire hazard. Burnt brick is increasingly used instead of wattle and daub and corrugate iron instead of thatched roofs. Corrugate iron is far from being an ideal roofing material as it radiates heat when exposed to sun and can be noisy during rainfall, but because of durability, it has become the preferred roofing material in rural hot humid zones, both in Asia and Africa. The floors in mud houses tend to be compacted soil, which are swept every morning but are never really clean. With increasing wealth these may be replaced with poured concrete making the floors easier to maintain. Despite these changes, the overall rural African house design, placed on the ground floor with impermeable walls, remains unchanged.

Figure 1: Typical traditional rural house in Magoda, Tanzania: a waddle and daub construction or mud house.

House design may have a considerable impact on health. Elevating a building, using air-permeable materials for walls and including windows are design elements that optimise airflow and improve ventilation. Improved ventilation results in less indoor air pollution that decreases the risk of acute respiratory tract infections and chronic respiratory diseases (Gordon et al, 2014; Vanker et al, 2017; Adaji et al, 2019).

The effects of airflow on comfort are less tangible but also important for health. The principal variables that define the comfort zone are temperature, humidity and airflow. In an environment where heat and humidity are fixed, airflow may be the only factor mitigating the acute discomfort caused by the climate. As evidenced by the popular use of fans, increasing the airflow in indoor spaces may make a hot humid environment bearable. By contrast, reducing airflow can make a hot humid environment unbearable (Knudsen et al, 2014). One of the unintended effects of mosquito nets is that they reduce airflow by 50% or more depending on the mesh size (von Seidlein et al, 2012). Lying under a bednet in a poorly ventilated room in a hot humid climate can be sufficiently uncomfortable to make sleep impossible. Thermal discomfort is one of the most frequent reasons why people say they do not use mosquito nets despite being at risk for malaria (even when nets are readily available and prevent itchy mosquito bites) (Pulford et al, 2011). Elevating houses not only makes them more comfortable and protects against flooding, they also reduce the density of mosquitoes and hence reduce the risk of vector borne diseases including malaria (Charlwood et al, 2011). In a study in Magoda, Tanzania *Anopheline* mosquito densities in the upstairs bedrooms in two storey buildings were reduced by 97% compared with mosquito catches in outdoor ground floor tents in close proximity and during the same nights (von Seidlein et al, 2017).

Aside from improving indoor comfort and protecting against respiratory tract infections and vector borne diseases, well-designed housing has the potential to protect against diarrhoeal diseases. In many rural areas no municipal water supply is available, and residents have to find their own water source which can be a nearby river, a well, or harvested water from roofs. Adding rainwater gutters to a roof and a water storage tank can be a cost-effective approach to supply water (Clasen et al, 2015). Adding a ventilated pit latrine improves hygiene and can reduce the risk of waterborne diseases. Altogether building appropriate housing has the potential to improve health, specifically reducing the three major causes of death in young children in sub-Saharan Africa: malaria, diarrhoea, and respiratory tract infections.

We sought to assess how an elevated, well ventilated Asian-type house would perform in an African setting. For this purpose, we brought a Thai construction team to Tanzania to build a typical north eastern Thailand bamboo house. To compare the relative comfort of living in a Thai-style house to a traditional African house we used psychrometric (not to be mixed up with psychometric) charts, a graphic representation of thermal comfort, based on temperature and humidity recordings in the new bamboo house and in a neighbouring traditional mud house.

Materials and Methods

The findings presented here are the results of a sub-study of the Healthy Homes Project. The project had two major phases. In the first phase a team of architects from Copenhagen, Denmark collected empirical data in two sites in SEA, Mae Sot, Thailand and Leyte, Philippines and two sites in sub-Saharan Africa (Basse, The Gambia and Magoda, Tanzania). The study found that elevated homes were the standard in rural Asia but absent from the sites in Africa. Building materials in sub-Saharan Africa were heavy and not air-permeable, in contrast to building materials in South East Asia, which were light and air-permeable. Based on climate data collected over a year, airflow and climate comfort were modelled using Computational Fluid Dynamics. The findings from the first phase found that constructing houses with air-permeable materials such as loosely spaced planks or bamboo cladding and large windows facilitate a relatively comfortable indoor climate. The findings from the first phase were published in 2014 (Knudsen et al, 2014).

In the second phase of the project six prototype houses were constructed by local teams in Magoda, Muheza District, Tanga Region, Tanzania. All houses were elevated, used air-permeable cladding, had a kitchen separated from living and sleeping areas, screened windows and a latrine built at some distance from the living quarters. Key characteristics of the newly constructed buildings were compared traditional homes in the immediate neighbourhood. The new design houses were 2·3°C (95%CI 2·2°C to 2·4°C) cooler and including elevated, single storey buildings had overall 86% (95%CI 76% to 93%) fewer mosquitoes than traditional homes. Qualitative research found that the new housing types were well accepted by the villagers. The findings were published in 2017 (von Seidlein et al, 2017). The Thai bamboo house described here was constructed in 2015 after construction of the six prototypes. The climate data of the Thai house were compared with data from the geographically closest traditional mud house.

Study site

Magoda (5°11'11.6"S 38°51'26.0"E) had a population of 2,934 individuals in 678 households at the time of the 2012 national census (Tanzania_National_Bureau_of_Statistics, 2016). Subsistence farming and informal trade are the major sources of income. The mean bedtime indoor temperatures, between 21:00 and 22:00, were highest between January and March, coinciding with the malaria season and lowest between June and August.

Climate data

Hourly measurements of indoor temperature and humidity were recorded in all study houses using HOBO data loggers (ONSET, Bourne, MA, USA). The data loggers were installed in the bedroom used by the household head were installed 500mm and 1000mm above the floor.

Psychrometric testing

The software package LadyBug (LadyBug Products, Athol, Idaho, USA) was used to estimate the percentage of time occupants of various house types spent in the comfort zone (Sadeghipour-Roudsari & Pak, 2013). Data collected on all days between 1. December 2015 and 31. May 2016 from 19.00-22.00h was included in the estimates. The assumed clothing rate, defined as light clothing (shorts and shirts), was 0.6, and the assumed metabolic rate was 1.1 (sitting). The comfort zone is defined by a polygon for temperature and relative humidity and an estimated percentage of people dissatisfied (PPD). The human energy balance model used by the psychrometric chart is the Predicted Mean Vote (PMV) model developed by P.O. Fanger (Fanger P, 1970). PMV is a seven-point scale from cold (-3) to hot (+3) that is used in comfort surveys. Each integer value of the scale indicates the following: -3: Cold, -2: Cool, -1: Slightly Cool, 0: Neutral, +1: Slightly Warm, +2: Warm, +3: Hot. The accepted range of comfort is a PMV between -1 and +1 and defines the area of the comfort polygon on the psychrometric chart.

Data management and analysis

Climate data were downloaded from each data logger at monthly intervals and transferred into a central database. Data collected around 21:30 +/- 30 minutes were used for the analysis. STATA 14.1 (StataCorp; 4905 Lakeway Drive; College Station, Texas 77845, USA) was used for statistical analysis of quantitative data.

Approvals/consent

A Clearance Certificate for Conducting Medical Research in Tanzania was obtained from the National Institute for Medical Research on 14th August 2014 (NIMR/HQ/R.8a/Vol. IX/1797) and extended on 14th January 2016 (NIMR/HQ/R.8c/Vol. II/555).

Figure 2: Harvesting bamboo in Amani forest, Tanzania

Results

The Thai team harvested bamboo locally (Figure 2) and built the bamboo house within two weeks. The new bamboo house occupied 38% more floor space (48m^2) than the traditional mud house (30m^2) which served as comparator (Table 2). The comparator traditional African house had four small windows, which were partially covered by plaster and curtains, whereas the bamboo house had six large, open windows and a highly permeable cladding which assures air exchange (Figure 3 and 4). Zone 1 is accessible through the ladder and serves as a semi-enclosed reception and social area which communicates freely with the surrounding space. Residents sitting in this area can freely see and talk with neighbours and family members passing by. Zone 2 and 3 are more enclosed to assure more privacy for the residents. The household head has his enclosed sleeping area. Other family members sleep in the areas to the left and the right of the house hold head.

Table 2: Comparison of the Thai bamboo house with the comparator traditional African house in the study site

	Thai Bamboo house	**Traditional African house**
Elevation	On stilts	None, on the ground
Cladding	Bamboo	Mud (wattle and daub)
Windows	Large, many	Few and partially closed
Floor space	48m^2	30m^2
Psychrometric score	85	34

Figure 3: Design of the Thai bamboo house compared with the traditional African house. Top row: Floor plan, middle row: Façade, bottom row: Section

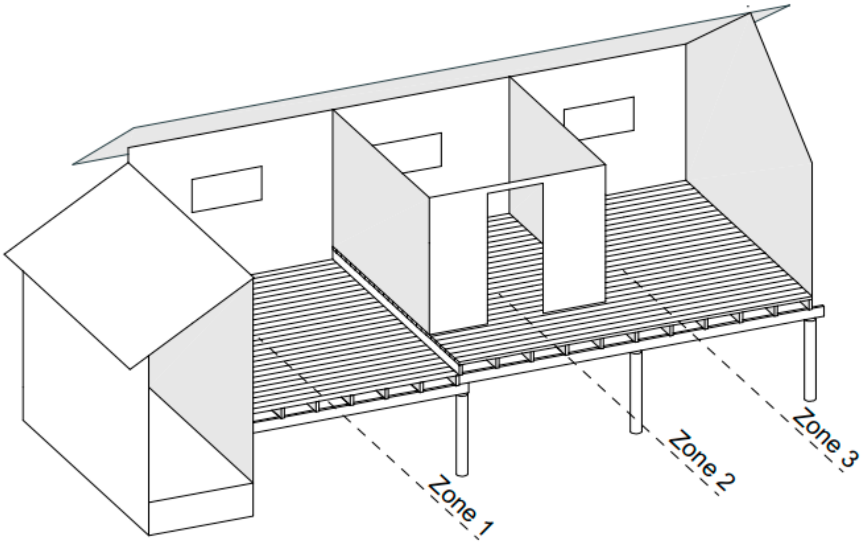

Figure 4: Isometric drawing of the bamboo house, where zone 1 is the entry area, zone 2 the sleeping area for other family members and zone 3 the sleeping area for the family head

The psychrometric assessment of the house indicated that residents in the bamboo house are likely to feel comfortable 85% of the time between 19:00 and 22:00 while the residents in the mud house would only feel comfortable PMV 34% during that time (Figure 5).

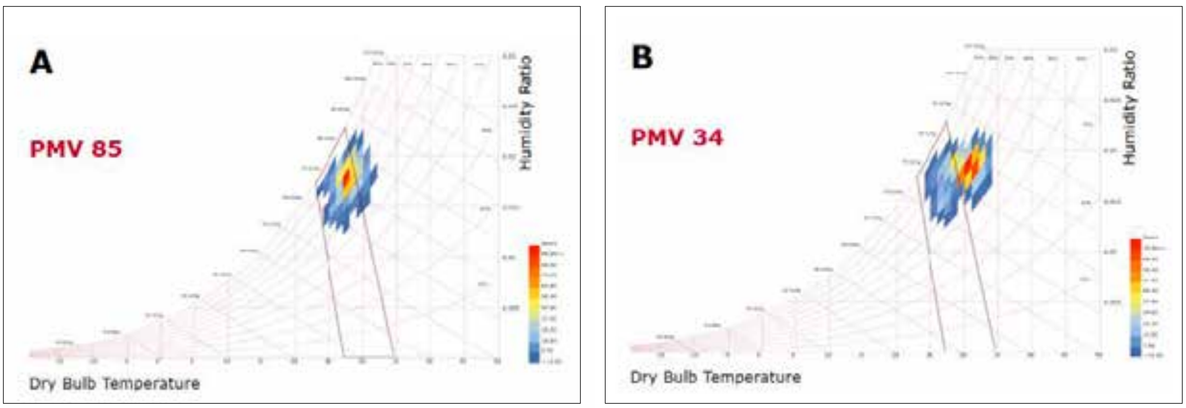

Figure 5: Psychrometric charts for the bamboo house (A) and reference house (B)*

*Data collected on all days between 1. December 2015 and 31. May 2016 from 19.00-22.00h.

When residents decide where to sleep and whether to use a bednet were included in the estimates. Points lying inside the polygon are considered comfortable, whilst those outside are uncomfortable. The predicted mean vote for the bamboo house was 85% compared to 34% for the WDC. The numbers represent the percentage of time the residents in each house feel comfortable.

As of the last study site visit in February 2019, the bamboo house has been used uninterruptedly since it was handed over to the residents in 2015. The residents have expressed a high level of satisfaction with their new building. Figure 6 shows the bamboo house at dusk illustrating the wide spacing of bamboo planks providing optimal airflow. In the background is the previous home that is now used as accommodation for guests and as a storage area.

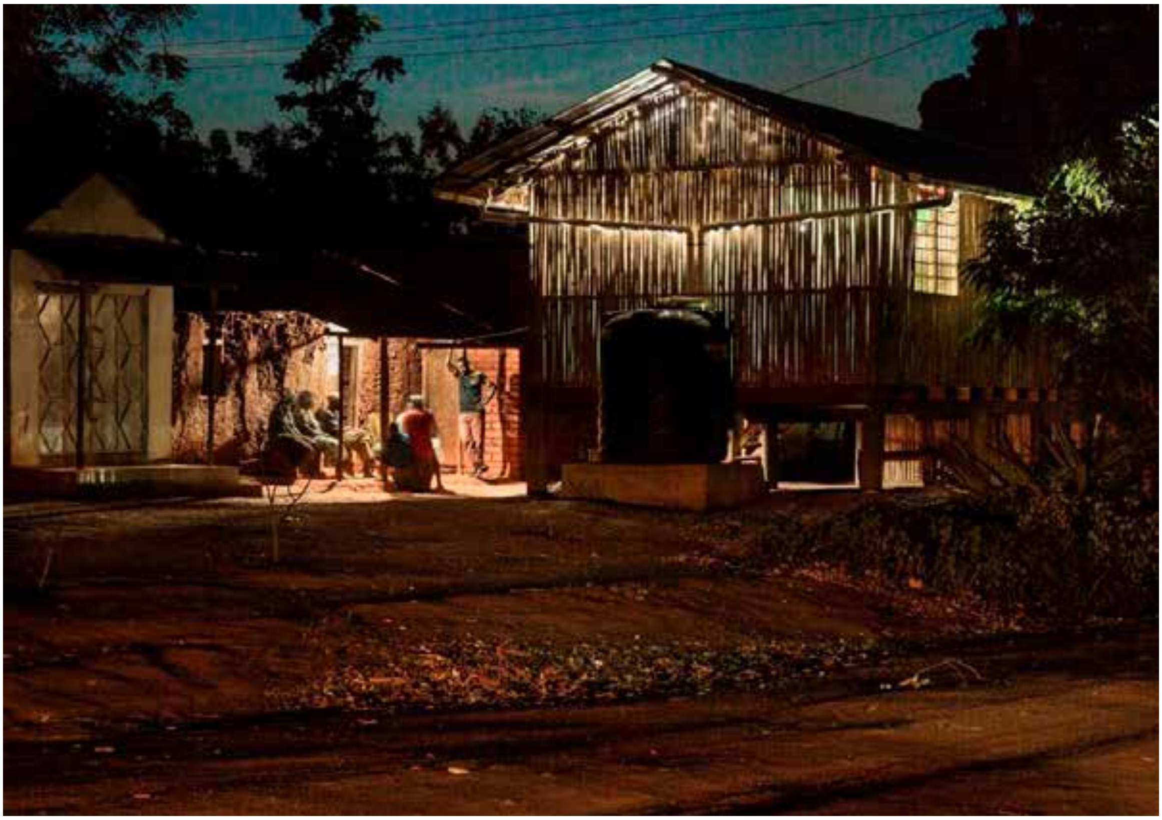

Figure 6: The completed bamboo house at dusk

Discussion

We found that bamboo, which grows in the Tanga region of Tanzania is suitable for construction but is not traditionally used as housing material. It is feasible to harvest bamboo in the surroundings of Magoda and to use it for house construction along the designs of those in Tak Province, Thailand. The elevation of the house and use of permeable walls optimise airflow, reduce the indoor temperature and improve the overall indoor climate. The indoor climate in the new bamboo house was substantially more comfortable than in the traditional African waddle and daub house, which served as the comparator. Based on a computational model, residents in the new bamboo home feel comfortable for 85% of the time between

19:00 and 22:00 compared to only 34% in the traditional African waddle and daub house. This three-hour period is the critical time when the decision where to sleep and whether to take the time to set up a bednet is generally made. It stands to reason that residents in a traditional home who feel already uncomfortable during this period are less inclined to use a bednet and may prefer to sleep outdoors compared to residents in a bamboo house. The hottest time of the year tends to coincide with the peak of the malaria season when the risk for malaria transmission is highest. Providing a more comfortable sleeping environment holds promise to increase bednet use in African villages and thus reduce malaria transmission.

The new bamboo house was immediately accepted by the owners and has been in use uninterruptedly since occupation. This is a much-welcomed surprise as there is no tradition of elevated buildings and bamboo walls which could have conferred the perception of less protection against the environment than a traditional solid mud walls.

We present here findings from a single house built by Thai craftsmen in Tanzania. The findings on their own cannot be extrapolated or generalised. However, the observations made around the bamboo house in Magoda described here corroborate the findings of a pilot trial in the same village, Magoda where 6 pilot buildings were compared to traditional housing the surroundings (von Seidlein et al, 2017). All pilot buildings were elevated, either single storey or double storey and used permeable cladding, loosely spaced timber, bamboo, or shade net. The indoor temperature difference between the new design prototypes and the reference houses between 21:00 and 22:00 h was 2·3°C (95%CI 2·2°C to 2·3°C). The mean comfort level measured as predicted mean vote, was 27% in modified traditional houses, in the traditional reference houses 47%, in the double-storey houses 79%, and in the single-storey houses 82%. In comparison, the bamboo house described here had the highest comfort level percentage of 85% of all assessed buildings. Mosquito densities which were not assessed in the bamboo house described here but were substantially reduced in new design houses. The overall reduction of all mosquitoes caught was highest in the double-storey buildings (96%; 95% CI 92% to 98%) followed closely by the reduction found in single-storey buildings (77%; 95%CI 72% to 82%) and lowest in the modified reference houses (43%; 95CI 36% to 50%), and unmodified reference houses (23%; 95%CI 18% to 29%; Figure 5). The reduction of anophelines alone was also highest in the double-storey buildings (97%; 95% CI 92% to 99%) followed by single-storey buildings (75%; 95%CI 67% to 81%) and lowest in the modified reference houses (33%; 95CI 26% to 43%), and unmodified reference houses (3%; 95%CI 1% to 7%). A formal qualitative assessment of the acceptability of novel design buildings in Magoda, Tanzania found a perhaps surprisingly high level of satisfaction of the residents with their novel design buildings. The six houses have been occupied by residents since the handover in 2015.

The population of Africa is currently estimated to be 1.3 billion. The population growth in Africa is predicted to double to 2.6 billion by 2050 (Pison G, 2017). This population growth will require around 400 million new homes in addition to the existing homes requiring rehabilitation and replacement by 2050. Such an expansion of housing stock will exhaust current timber production in the near future. With already rapidly increasing timber prices prospective homeowners continue to use waddle and daub structures or, if they can afford it, tend to choose concrete and steel for new buildings, which again raises questions regarding the sustainable supply of these building materials. Bamboo grows well in sub-Saharan Africa but there is currently no tradition of using bamboo for house construction and little interest to produce bamboo commercially as a structural material. Our findings suggest that there could potentially be a considerable and rapidly expanding market for bamboo as a sustainable construction material in Africa.

Most African regions have experienced a change in climate over the last decade. Seasonal patterns hold no longer, and temperatures show an overall increase. It is not unreasonable to assume that temperatures will continue to rise. Providing air-conditioning for the rapidly increasing housing stock will not be sustainable. We identify here a sustainable approach to provide indoor climate comfort by means other than air conditioning. Learning from Asian experience suggests that people residing in Africa, particularly in rural areas would be better served by Asian style elevated houses with air-permeable cladding than the traditional ground level mud or brick constructions.

Not only do we believe that novel design housing provides more indoor climate comfort compared to traditional African housing we also hypothesize that novel house designs will have beneficial health effects. Specifically, elevation of bedrooms reduces mosquito density. Better indoor air-flow increases the probability that residents will use bednets regularly. The combination of reduced mosquito density and increased regular use of bednets may result in a substantial reduction in malaria transmission. Vector control measures in malaria control rely currently heavily on insecticides, e.g. indoor residual insecticide spraying and long-lasting, insecticide-treated bednets. Overreliance on insecticides has historically proven to be a less than promising strategy. New powerful insecticides are introduced, their market share increases rapidly, resistance emerges and spreads, new insecticides or combinations of insecticides are introduced, the cycle repeats itself. Separating vectors from the human host by physical barriers such as the elevation and screening of bedrooms may lead to a decrease in the demand for new insecticides and thereby slow insecticide turnover. Improved airflow may also reduce the risk of respiratory tract infections. Indoor cooking in poorly ventilated living and sleeping areas is likely to put residents at an increased risk for a range of respiratory illnesses which can be curtailed by novel design housing. For little extra cost novel design houses can be equipped with gutters and water storage tanks to allow rainwater harvesting and the construction of hygienic latrines. We are currently constructing 110 novel design houses in Mtwara, Tanzania to assess the benefit afforded by novel design housing against the three “childhood killers”, acute respiratory tract infections, diarrhoea and malaria

In conclusion, a typical Thai bamboo house was successfully constructed by a team of Thai craftsmen in Tanzania using locally sourced bamboo. The new bamboo house provided a substantially more comfortable indoor climate compared to traditional housing. The residents were happy with the house design and have made use of the new house up to now. Novel design housing holds considerable promise as a sustainable approach to provide housing for the rapidly expanding population of Africa and may carry health benefits. The wider use of novel design homes following an Asian design model is highly recommended for people living in the hot humid regions of Africa.

Contributors

LvS an JK conceived the study, TR designed the bamboo house and managed the Thai construction team. KI and SM supported the construction. KI drafted the line drawings and took the photos. JK executed the psychrometric assessment. LvS wrote the first draft of the paper. JD and CK provided administrative support for the project. All authors reviewed and edited the final manuscript.

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About the authors

Lorenz von Seidlein has been working on global health for the last 25 years based in West Africa, South Korea, East Africa, Australia and most recently Thailand where he is employed by the Mahidol Oxford Research Unit. He is coordinating malaria elimination projects in Asia and working on a project in East Africa to provide better health through improved housing.

Tip Ruchaitraku, had a number of administrative roles in the Shoklo Malaria Research Unit in Mae Sot and is currently overseeing construction projects in Tak province, Thailand.

Konstantin Ikonomidis is an architect with a special interest in building homes in extreme climates. After working in East Africa, Denmark and Sweden, he is currently designing housing projects in Greenland.

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Jakob B Knudsen is the head of the School of Architecture at The Royal Danish Academy of Fine Arts in Copenhagen, Denmark. He is also the principal of the architecture practice Ingvartsen. Jakob has a longstanding interest on the influence of housing on health and is looking for new approaches to improve heath through improved house designs.

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