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Jakob Knudsen, Lorenz von Seidlein
Healthy Homes in Tropical Zones. Improving Rural Housing in Asia and Africa
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Early nomadic shelters, including caves, animal skin tents, and igloos, were used for protection against the wind, rain, snow, sunlight, and other forces of nature. These basic homes also provided defence against predators and were used to store a few important possessions. They were temporary, and proximity to a water source was of prime importance.

Health and comfort were not yet under consideration. As civilization evolved, housing became more permanent, with increasing attention to well-being. The housing and utilities available in rich countries are vastly different from those in poorer settings. Unlike in industrialised countries where piped-in water, indoor toilets, and sewage systems are the norm, in the developing world these facilities are often not available. Waterborne enteric diseases, preventable by the supply of safe water, hand washing, and appropriate sanitation, continue to be a major disease burden in poor countries. Vector-borne diseases that can be controlled by screening and other barrier methods also remain an important health problem. Safe, comfortable, and healthy homes are an essential requisite for healthy living around the world, irrespective of culture or socio-economic status.

Throughout the tropics there is a huge diversity in house design and use of building supplies based on centuries of indigenous experience, customs, and availability of local resources for construction. These differences in building style and materials affect the indoor conditions and comfort of occupants, which in turn influence the occupants' exposure to certain infectious diseases. In this book the authors describe the architectural designs and materials of rural houses in two countries in Asia (Thailand, Philippines) and two in Africa (The Gambia, Tanzania). They analyse the effect of design on the indoor climate and relate these factors to health, notably the risk of mosquito-borne infectious diseases such as malaria. Based on their findings and a detailed understanding of local building styles, they describe a series of house modifications that could enhance comfort whilst reducing health risks.

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Health and comfort were not yet under consideration. As civilization evolved, housing became more permanent, with increasing attention to well-being. The housing and utilities available in rich countries are vastly different from those in poorer settings. Unlike in industrialised countries where piped-in water, indoor toilets, and sewage systems are the norm, in the developing world these facilities are often not available. Waterborne enteric diseases, preventable by the supply of safe water, hand washing, and appropriate sanitation, continue to be a major disease burden in poor countries. Vector-borne diseases that can be controlled by screening and other barrier methods also remain an important health problem. Safe, comfortable, and healthy homes are an essential requisite for healthy living around the world, irrespective of culture or socio-economic status.

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Chapter 1: Introduction

Healthy homes:
a story of unintended consequences

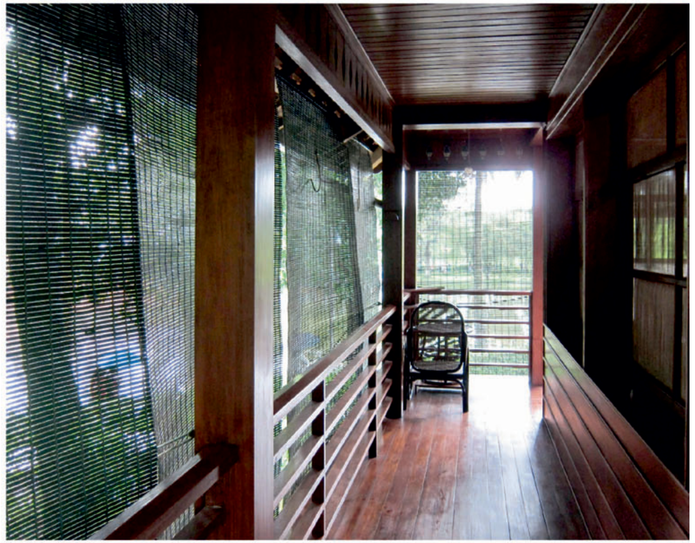
Early nomadic shelters, including caves, animal skin tents and igloos, were used for protection against the elements (wind, rain, snow and sunlight)[1]. These structures provided defence against predators and storage facilities for a few important possessions. These early buildings were temporary, and proximity to a water source was of prime importance. For the hunters and gatherers, shelter was for survival. Health and comfort were not yet under consideration.

As civilization evolved, housing became more permanent, with increasing attention to well-being. Unlike in industrialised countries where piped-in water, indoor toilets and sewage systems are the norm, in many developing countries these facilities are often not available. Waterborne enteric diseases, preventable by the supply of safe water, hand washing and appropriate sanitation, continue to be a major disease burden in poor countries. Vector-borne diseases such as malaria, filariasis, leishmaniasis and dengue fever continue to cause illness and death in these settings. People living in tropical regions where these infections are endemic have adapted their housing structures in different ways to prevent entry of disease vectors. The more affluent segments of society protect their houses through structural barriers, including concrete walls and floors, screened or glass windows and sealed eaves. This building strategy is quite effective in limiting the entry of pests but also prevents airflow and ventilation, leading to the need for indoor fans and air-conditioning, which may be available to a small elite but are too expensive for the larger majority of the population. A different approach is used in traditional tropical Asian housing. Instead of building expensive fortresses that limit the entry of pests, as well as ventilation, low-cost Asian homes are light and open. These homes use other techniques to deter pest invasion whilst enhancing ventilation. Huts are raised above the ground to reduce the entry of mosquitoes, ants and fleas, increase airflow and protect against flooding. Secondly, houses are built of porous materials such as bamboo lattice or wooden planks to allow cooling by airflow. Attacks from insects are prevented by the use of bednets tucked into tightly woven straw mats laid on the floor and used as beds. Bednets were used in Asia long before large donor and aid agencies started promoting them, and they continue to be popular.

In contrast to Asia, on the African continent where the incidence of vector borne diseases may be even higher than in Asia, low-cost housing evolved in a different direction. Walls tend to be constructed of mud or brick with few if any windows. Floors are rarely elevated; the house construction materials are too heavy for this design. Airflow in such houses is minimal. Thick walls and minimal airflow may be appropriate in dry desert climates where the coolness of the night is retained in the walls, which warm up slowly during the day and in turn release heat during the night. But in large regions of sub-Saharan Africa where it is hot during the night and even hotter during the day, mud huts with minimal ventilation do not enhance human comfort. Smoke from indoor cooking increases human discomfort in mud huts. Indoor cooking produces indoor air pollution and increases the risk of respiratory infections. There is no unequivocal evidence that indoor smoke reduces the burden of mosquitoes and malaria[4]. When used correctly, insecticide-treated bednets have been shown to be highly protective against malaria[5]. Although donors and aid agencies have been aggressively promoting the use of bednets in Africa, the results have frequently been disappointing. The use of bednets tends to drop off within months of the distribution of nets[6]. The most frequently cited reason why sub-Saharan Africans are reluctant to use bednets is the discomfort associated with their use[6]. The little ventilation that can be detected in a smoky mud hut is reduced by half inside a bednet[7].

Poor housing allowing mosquito entry has been identified as a risk factor for malaria for more than two decades[8]. A series of studies have demonstrated that open eaves in particular are a critical risk factor for insect entry into African huts[9-13]. This observation is best explained by the attraction of mosquitoes to human odours that leave the house through the eaves. Mosquitoes fol-

Ho Chi Minh's house in Hanoi, Vietnam, took the design elements of Asian low-cost housing to the extreme. The house is elevated on stilts, large windows assure optimal ventilation, and bednets protected its residents against mosquitoes during the night. The house is now a museum.



lowing human scent enter through the eaves and find their blood meal. Recognising this structural vulnerability of huts Lindsay and co-workers recommended that eaves be closed[14] and they showed that screening of houses substantially reduces the number of mosquitoes inside the house[15]. The aim was to "seal" these mud huts in hot humid settings to prevent the entry of mosquitoes.

Unintended consequences

Interventions that aspire to solve complex problems sometimes lead to unintended consequences, ranging from beneficial to detrimental. The well-intentioned quest for healthy homes has led to several negative unintended consequences. For example, engineers in the Roman Empire required a malleable metal such as lead for the fabrication of pipes. The effects of lead poisoning, particularly permanent learning and behavioural disorders in children, even at very low lead concentrations, is now well known. Another example is the use of asbestos in buildings. Asbestos was highly valued as a building material for its tensile strength, insulation and fire resistant qualities. In addition, asbestos is affordable and was much used as a building material around the world in industrialised as well as in resource-poor countries from the end of the 19th century to its peak of production in 1975. Unfortunately asbestos fibres can be inhaled and cause havoc in the human respiratory tract. One outcome is a bilateral progressive fibrosis known as asbestosis[16]. Even more worrying is the close association between asbestos exposure and mesothelioma, a neoplasm with particularly poor prognosis[17,18]. Over the last 30 years the problem has been better understood; asbestos is no longer used as a building material and is now carefully removed from many buildings in an attempt to minimise human exposure to this toxic material.

Measures to reduce contact between mosquitoes and human hosts, such as the sealing of eaves, screening of windows and even the use of bednets, may have unintended negative outcomes. Each of these interventions has structural consequences for the indoor space, which may be overlooked or thought to be insignificant. During the hot season each of these interventions adds to the effects of an already uncomfortable indoor climate. People living in African mud huts have to decide whether they prefer the discomfort caused by a bednet or the mosquito nuisance. Once mosquito densities drop, mosquito nets are often no longer used in spite of persistent low levels of disease transmission. Sealing the eaves may have larger and wider reaching negative consequences.

As shown in chapter 13, air entry through eaves is critical for airflow and air turnover. Once airflow in a mud hut is reduced, the indoor cllimate can become so uncomfortable during the hotter months that the residents prefer to sleep outdoors. Worse, reducing air changes below an acceptable minimum level, especially in the presence of smoke-related indoor air pollution, may aggravate the risk for respiratory conditions and promote the transmission of respiratory infections like tuberculosis[19].

Thus, hermetically sealing homes to prevent the entry of mosquitoes has unintended negative consequences and alternative approaches need to be considered. We studied traditional mud huts in two malaria-endemic sub-Saharan African countries, Tanzania and The Gambia. Indoor temperatures are highly uncomfortable during the hot season, reaching up to 49°C during the day. If windows were present they were usually small. Where eaves are open they are the major source of air exchange, as we will show in the following chapters. The evolution of huts in Asia suggests alternative approaches. Elevating huts not only increases airflow, it also reduces the mosquito density. Besides this, elevating buildings protects against flooding, invasion of vermin and infections from soil-transmitted helminths. 3-D modelling allows us to evaluate individual structural elements and optimise huts as shown in chapter 14. If eaves are closed in mud huts, the reduction in airflow has to be compensated with large windows on opposing sides of the room. Screening and bednets attenuate airflow but reduce the exposure to mosquitoes. Ignoring the discomfort created by interventions against vectors is short-sighted, since such interventions will not be sustainable.

In this book we describe the architectural designs of rural houses in two countries in Asia (Thailand, Philippines) and two in Africa (The Gambia, Tanzania), analyse the indoor climate of local houses in these settings as an outcome of design and determinant of comfort, and relate these factors to health, notably the risk of mosquito-borne infectious diseases such as malaria. Based on these findings and intimate understanding of local building styles and preferences, we describe a series of house modifications that could enhance comfort whilst at the same time reduce health risks.

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Chapter 2. **Climate**

Temperature, humidity and airflow are the three principal conditions that determine whether humans will feel comfortable in a given climate. Most people feel comfortable when the indoor temperature is between 22 °C and 30 °C and the relative humidity is between 20% and 80%. Airflow becomes critical at the upper limits of the thermal comfort zone. On a hot summer day we feel much more comfortable when there is a little breeze. This is witnessed by the hordes of people crowding on beaches during hot summer days in the hope to get a little bit of relief from the heat.

One approach to creating a thermal comfort is air-conditioning. It is perhaps no coincidence that the financial capitals of Singapore and Hongkong only emerged after universal air-conditioning at the workplace had become available. Prior to air-conditioning, high-efficiency offices were primarily located in the Northern Hemisphere. As mentioned in the previous chapter, there are several disadvantages to universal air-conditioning. Besides the cost for buying the appliance air-conditioning requires a permanent power supply, which is neither available nor affordable for large populations.

There is currently great interest in designing structures adapted to human needs without the use of air-conditioning. It is widely accepted that there is no single approach that works best in all climate zones. Some 2000 years ago the Roman architect Vitruvius wrote in the sixth of his *Ten Books on Architecture*: "One style of house seems

Figure 2.1. The predominant climate zones.

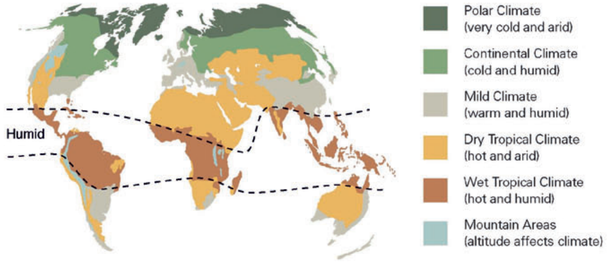

Figure 2.1. Contemporary building materials in Thailand: cement stilts, thatch and bamboo panels for roof and walls respectively.

appropriate in Egypt, another in Spain, a different kind in Pontus, one still different in Rome and so on with the lands and countries of other characteristics." Climate zones around the world have been classified by temperature and humidity (Figure 1).

The focus of the Healthy Homes project is the adaptations of houses to tropical climate found in the populated areas of sub-Saharan Africa and Asia. Tropical climate is characterised by stable high humidity and high temperature, which vary only slightly between day and night, as well as across the seasons throughout the year. In forested areas there is continuous precipitation assuring very high humidity. If sunlight is not attenuated by a heavy cloud cover there is a considerable glare. The Asian response to tropical climate is open skeleton structures with wide roofs to divert rain and light. Building materials such as bamboo are lightweight and assure easy ventilation. The floors and terraces tend to be elevated on stilts, which increases airflow and where needed provides some protection against flooding.

In contrast to the hot, humid climates of the tropics hot, dry desert climates are characterised by large differences in temperature between day and night, mild winters and extreme summers. Blue skies and intense sunshine are present throughout most of the year. Drought is usually a larger problem than floods. People residing permanently in desert climates tend to use massive structures constructed out of heavy materials such as stone, which can hold a large thermal load to stabilise indoor climate between the outdoor extremes. Such massive buildings tend to warm up slowly during the day, radiate heat during the night while slowly cooling down and attenuate the outdoor heat during the day. Desert climate tends to be dry; high humidity is not a major issue and ventilation has a relatively low priority. Adaptation to a desert climate is in many ways the opposite of the requirements in a hot, humid, tropical zone.

The inappropriate use of desert style buildings in a tropical climate is exemplified by Stonetown in Zanzibar, United Republic of Tanzania. The spice-growing archipelago of Zanzibar was part of the Omani sultanate whose rulers brought their architects and builders to Zanzibar to construct a city following the Omani style. Stonetown consists of massive stone structures with few or no windows and narrow roads that prevent reasonable airflow between and into buildings. The equilibration of heat between day and night, most welcome in desert climates, does not take place in Zanzibar as it is hot and humid around the clock for most of the year. At midday, when it is hottest, the narrow alleyways between the edifices radiate trapped heat, and during the monsoon season water collects and runs through these passages. In humid heat without air-conditioning, it is dark and uncomfortable within Stonetown's massive walls day and night. Although considered a UNESCO heritage site because of its unique fusion of Arab and African culture, Stonetown is a climatological calamity for Zanzibaris who have to live and work there. Today tourists are a major source of income for the island and air-conditioning units have been retrofitted in a large number of the old stone buildings. This results in overloading of the available supply of electricity and consequently regular power outages.

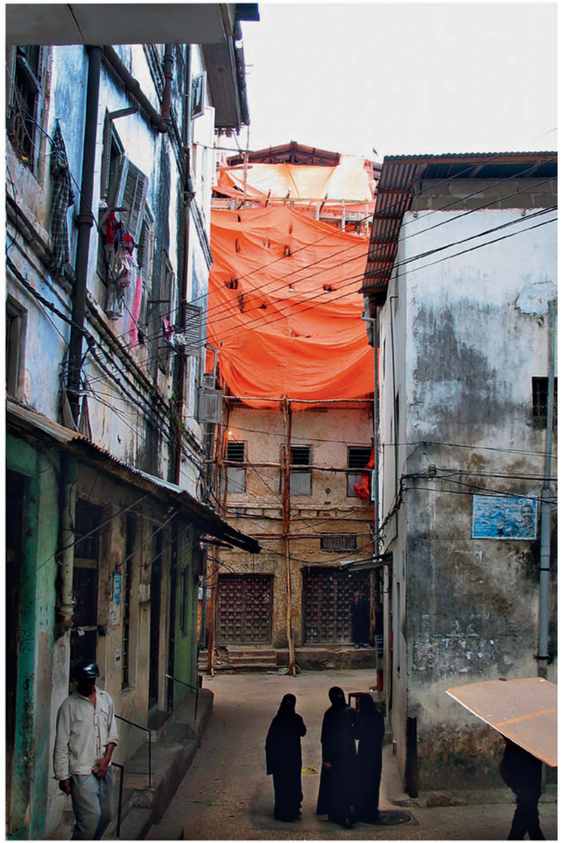

Figure 2.2. Stonetown, Zanzibar, possibly one of the most inappropriate architectural technology transfers ever. Massive stone buildings, perfectly suitable for a desert climate, have been erected in the tropical climate of East Africa.

The human comfort zone: it started in Copenhagen…

The relationship of the three principal variables that determine thermal comfort is illustrated in Figure 3. Most people feel comfortable in an indoor temperature below 30 °C and this upper limit decreases with increasing relative humidity above 50%. If the relative humidity reaches 75% very few people feel comfortable at indoor temperatures above 25 °C. Airflow can extend the comfort zone upwards, which allows residents to remain comfortable at higher temperatures than would be possible otherwise. At a wind speed of 1 metre/second an indoor temperature of 35 °C and a humidity of 70% may be tolerable. However, a wind speed of 1 metre/second is rather intrusive, for example requiring the holding down of papers on the desk so they do not get blown away. A more realistic speed is perhaps 0.1 metre/second, airflow that can be barely perceived and requires precision instruments to be measured accurately. But even such a minimal breeze can make the difference between comfort and discomfort at the upper edge of the comfort zone.

In 1970 the Danish researcher Ole Fanger used climate chamber research to define the comfort zone based on the above-mentioned conditions: temperature, humidity and airflow. He added the parameters of human metabolism and clothing to define the individual comfort zone[2]. By standardising human metabolism and clothing Fanger developed a model – called the predicted mean vote (PMV) – which allows one to estimate the optimal climate conditions for a group. The PMV is defined as the mean thermal sensation vote on a standard scale for a large group of persons for any given combination of the thermal environmental variables at a set activity and clothing level. The variation in climate tolerance for any group of people is normally distributed. Over a range of temperatures there will be some individuals who consider it too cold or too hot, but the large majority of respondents experience thermal neutrality, i.e., no discomfort. Accepting that it is impossible to satisfy all people all the time the predicted percentage dissatisfied (PPD) can be estimated as:

The model is now more than 40 years old and remains the preferred method for evaluating thermal comfort[3]. Indeed the global industrial standards for thermal comfort (ISO, ASHRAE) are based on Fanger's method. That does not mean to say that Fanger's method has not been criticised; specifically the question has been raised whether the thermal comfort requirements of Danish college students (on whom the studies were based) are relevant to populations in tropical settings. A range of studies have been conducted to replicate Fanger's findings and extend them to other geographic settings. Among Singapore college students (n=32) the preferred temperature was 25.4 +/–1.2 °C, not significantly different from respondents in colder zones[4]. In Indonesian office

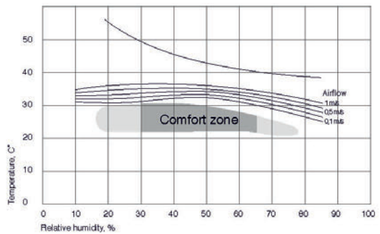

Figure 2.4. The human thermal comfort zone (after Koenigsberger)[1].

workers (n=596) the neutral temperature was 26.7 °C, i.e., respondents preferred slightly higher temperatures than those in Copenhagen[5]. In Hongkong (n=2173) the preferred temperature was 22.5 °C[6]. A second criticism is whether findings from air-conditioned research chambers can be extended to naturally ventilated spaces. A study in Bangkok (n=1100) indicated that the range of tolerated climates was broader in naturally ventilated spaces and the upper limit of thermal comfort was higher in naturally ventilated spaces than in air-conditioned spaces[7]. A study in Pakistan (n = 7112) found that there was "generally little discomfort" at temperatures between 20 ° and 30 °C in naturally ventilated spaces[8].

In conclusion, the Fanger model of a thermal comfort zone has been around for more than 40 years, is more popular today than ever and there has been no other realistic alternative proposed to evaluate indoor climate. The concept helps to understand why subtle changes in airflow at the upper edge of the comfort zone can predict whether the indoor climate would be tolerable or not. The actual numbers used in the models are not free of controversy as there are subjective variations in the perception of thermal comfort between populations as well as between naturally ventilated and air-conditioned spaces.

And what does all this mean for homes in rural sub-Saharan Africa? In contrast to the open Asian structures described above, rural sub-Saharan African homes have not evolved to optimise the thermal comfort zone. There is little if any emphasis on ventilation in rural sub-Saharan African homes. Consequently airflow is minimal and usually not planned. Many homes have no ceiling and the gaps between the top end of the wall and the roof (eaves) allow some minimal airflow, especially if there is an open door or window. Indeed airflow is not necessarily considered a positive force; instead it is rather associated with the movement of mosquitoes and other insects and hence prevented. This situation is frequently aggravated by smoky fires, which are employed to repel mosquitoes. In a sweltering hot, humid night there remains little choice but to find some coolness outside the home. How these sleeping arrangements are perceived by the outsider has been vividly described by Stuart Stevens[9] in a book describing his travels around sub-Saharan Africa:

"With a certain grace, the chief motioned us to enter his hut.

It had two rooms, a dirt floor and thick mud walls. The three beds were grouped together in the first room, the bamboo slats covered with reed mats. A kerosene lamp gave off a soft, tentative light. Except for the door covered by a mat, there were no openings for air, it was very hot, with a layer of light smoke hanging like ground fog.

We lay down. The chief and his two wives and two young children moved into the other room, separated from us by a low mud wall. They spoke softly in Sango; somewhere outside a radio played the national station.

I woke in a slick sheen of sweat, coughing in a smoky room. … I staggered outside. The air felt almost cool and sharply clean. Around the smouldering fire in front of the hut a family lay spread out on mats: four children and a young mother and father. They were talking and I wondered if that was how it went all night, bouts of dozing and conversation, a gentle bit of laughter. … In Mauritania some years ago, a Peace Corps volunteer, appalled by the smoky, unventilated huts in which the natives lived, proposed quite forcefully that a centre chimney be added. The huts were free of smoke, with the result that mosquitoes no longer stayed away and malaria rates soared. I thought about this lying on the ground while whole squadrons of flying beasts launched saturation attacks on my body. Nodding to my neighbour, I moved between two children, inches from the smouldering mosquito-banishing fire. A light, pleasant rain began to fall."