Lightweight tropical: Reconnecting construction technologies with thermal comfort

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ABSTRACT: The processes of modernization and globalization unfolding throughout South-East Asia reveal a concerted push to use masonry construction technologies in the housing market. This is in part due to desires to engage with imported ideologies but pragmatic issues such as the effects of deforestation make this trend all the more apparent. This paper critiques the use of masonry construction technologies in tropical climates and addresses relationships between construction technology and thermal comfort. Users have typically described non air-conditioned masonry houses as hotter than traditional lightweight timber houses during the day and difficult to cool – particularly at night. However existing literature suggests that masonry houses would be cooler than lightweight houses in the early morning due to time lag effects. This paper introduces a pilot study that uses comparative temperature measurements to evaluate these claims. It challenges the claims made in the literature by revealing that lightweight timber houses perform more effectively than masonry houses throughout both the day and night with the highest difference being in the hours when the house is used for sleeping. It goes on to argue the case for alternate lightweight construction materials with similar properties to timber and outlines the advantages of housing systems based on fibre-cement wall panels.

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INTRODUCTION

Contemporary development processes in South-East Asia reshape the ways tropical houses are imagined and conceived by their owners. Traditional practices, self-build and incremental construction techniques and lightweight construction technologies are being neglected in favour of techniques that are seen as being more ‘efficient’ or ‘modern’. This type of transformation has technical and cultural implications, occurs in urban, suburban and rural areas, and has an impact on the region’s future development. This paper concentrates on the effect upon thermal comfort when imported models supersede traditional housing systems in rural areas.

Depending on the country concerned there have been varied degrees of engagement with new housing materials. The countries with closer connections with other industrialised nations have adapted these new technologies more readily – most notably Singapore, Thailand and Malaysia. Other countries lag behind – Cambodia, Laos, Burma, and the remote Indonesian islands – while most others sit somewhere between. However it is the rural areas that have had the least amount of change to the housing culture and generally this has been occurring only within the last ten years – if at all. This change from lightweight ‘natural’ materials and post and beam construction systems has heralded the introduction of load bearing walls based on masonry technologies. While masonry has been a dominant material in the urban fabric of these nations for two centuries – brought by European and Chinese traders – it has rarely made its way to the housing systems in rural areas. However this is no longer the case and there are two main reasons why this is so.

The first issue is of a pragmatic nature and is centred upon the effects of deforestation. South-East Asia’s forests are threatened by industrialization, overpopulation and corruption (Dauvergne, 1997; Global Witness, 2002). The Food and Agriculture Organization of the United Nations (FAO) reported that Indonesia and Malaysia were losing forest cover at six times the global average. Burma was worse at seven times, whilst Thailand and Cambodia lost forest cover at three times the global average (FAO 2001). The Bangkok Post has reported that the illegal logging industry continues despite the government’s 1989 moratorium (Bangkok Post, 1 October 1998). Australian newspapers have reported that a retired Thai Prime Minister was implicated along with the Cambodian Government in the illegal logging trade (The Age, 24 January 1997). Another suggested that the Cambodian forests would be commercially exhausted within five years and there was little hope for sustainable forest industries (The Australian, 9 June 1999). Attempts to regulate the timber trade have repeatedly failed to make South-East Asia’s timber industry sustainable. The net effect is that timber is unaffordable for the rural poor.

The second issue concerns the introduction of new ideologies – in particular the changing aspirations of people in these rural communities. Whereas the people living in rural communities might have once been satisfied with their modest house constructed from timber, bamboo and thatch they are now exposed to images of suburban houses in two main ways. Firstly patterns of migration mean that rice farmers travel to city areas when planting and harvesting

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are complete. Here they work as taxi drivers, as construction and as factory workers or bar girls and are exposed to new lifestyles based on consumption and status. Secondly the television acts as a conduit between city and rural lifestyles. Popular television soap operas are commonly set in lavishly decorated houses with generously proportioned spaces, Grecian columns and marble statues (Hamilton 1992). This pattern holds true throughout South-East Asia – even in the poorest regions the population has access to televisions, and the soap operas and dramas are frequently the most popular forms of family entertainment. Desirable lifestyles, images of modernity and the cult of celebrity are enmeshed with specific house types and then packaged as symbols of status. Consequently the rural poor have begun to identify with the lifestyles of the upper and middle classes and use these to help redefine their own aspirations (O’Brien 2005). While it is difficult to demonstrate a causal link, changes to housing types in rural South-East Asia have coincided with the proliferation of television and it seems pertinent to investigate how images of ‘modern’ housing might be reinterpreted in rural locations.

As the existing vernacular housing stock reaches the end of its lifespan new construction techniques must emerge. Migration and the images seen on television offer rural residents a clear opportunity to engage with new housing types – albeit on a more modest budget. However it remains to be seen if the rural poor are getting value from their masonry houses. Do these houses provide the same levels of comfort as attributed to the traditional timber houses? Are other construction materials more suitable? This paper addresses these questions by first discussing the attributes of the traditional vernacular house and making comparisons with the common non air-conditioned masonry varieties now becoming commonplace in rural areas of South-East Asia. It then goes on to outline some alternate materials and construction systems, based on lightweight technologies, that connect more closely with tropical climates.

1. THE TRADITIONAL LIGHTWEIGHT VERNACULAR

The development of the lightweight tropical house in rural areas of South-East Asia has been well documented (Oliver 1997, Chaichongrak et al 2002, Waterson 1997, Dumarcay 1985, Gibbs 1987, Dall 1982, Srisuro 1995). With minor exceptions timber posts and beams were embedded in the earth in a modular formation to define the outline of the house. A series of timber beams were attached to these posts to form a frame that in turn supported the floor and roof. Infill walls were prefabricated and attached to the frame – poorer families built their panels with woven bamboo or grasses and wealthier families commonly used timber. Roof materials could include leaves or grasses while wealthier families used small interlocking clay tiles (Fig. 1).

![Figure 1: South-East Asian tropical houses – Four types](image)

Most of the literature discussing South-East Asian housing has emerged from a predominantly descriptive taxonomy concentrating on the vernacular timber housing of the region’s most wealthy areas. Wealthier regions have traditionally been seen to demonstrate the pinnacle of the tropical style whilst the housing (and to a degree the culture in general) of the poorest regions tends to be marginalized by scholars. The marginalization of the poorest community’s housing culture is further compounded by the simplicity of analysis that typically concerns itself with describing traditional uses, construction technologies, materials and forms. Oliver (1997) adds to this material by briefly comparing regional differences between the houses in Thailand, Indonesia, Malaysia, Cambodia and Laos without speaking more broadly of housing culture. The consensus reveals that lightweight construction technologies enabled houses to be built quickly; houses could be easily extended if the family’s fortunes increased or enlarged to reflect the owner’s status. Timber houses were carefully designed to suit the hot and wet climate – sleeping spaces were raised above the ground to catch cooling breezes and during the day the undercroft below the house was used as the main living area.

As outlined in the introductory section, a series of factors have worked to reshape traditional patterns of construction. Deforestation and changing household aspirations have introduced new construction technologies and production methods. The lifespan of timber houses is somewhere between 25 and 40 years but it is no longer possible to view them as viable solutions to the housing needs of rural communities. Despite talk of the need to establish sustainable methods, the research revealed that residents have begun to adopt masonry construction techniques as they build new houses. Masonry houses can appear to be a poor substitute to the traditional models on both aesthetic and practical grounds. Whilst aesthetics are hard to value, particularly across cultural borders, the practicalities of this new type of housing can be measured in various ways. This section has been based on research undertaken by the author in Thailand between 1999 and 2005 including interviews, observation, physical trace analysis, photographic surveys and spatial syntax analysis. Much of this work has been based at Ban Rai Kok village – a settlement 250 kilometres from Bangkok covering eighteen hectares and ninety-two houses, seventy outbuildings, three shops, one food stall and a series of community buildings. This village is typical of the villages in a region that includes the rural parts of northern and northeastern Thailand and parts of Cambodia and Laos. Here the housing culture is not framed within political boundaries as much as it is by the shared lifestyles, economies, food, religion and social networks of the people living within the Mekong River basin. Like the many thousands of villages in these regions this is a poor community based on a mix of farming and factory economies.

The research revealed that residents have begun to adopt masonry construction techniques as they build new houses but that some disquiet remains about masonry as the primary construction material. Interviews reveal that on the one hand masonry houses have traditionally been recognized as symbols of wealth and status, but on the other there is no contemporary alternative due to the lack of affordable timber. The two main criticisms that came out of the interviews are that masonry houses are hotter than timber alternatives and that masonry construction is used to build houses that frequently diminish community life. Issues regarding community life have been addressed in previous research undertaken by the author (O’Brien 2004) and this paper focuses on the issue of thermal comfort.
Despite the resident's capacity to adapt to new technologies there is unease at the way user comfort has been diminished by the widespread adoption of the masonry bungalow type. During a series of open-ended interviews conducted in a variety of villages in northeastern Thailand many residents complained that masonry houses are too hot and unfavourable comparisons were typically made with the perceived 'comfort' of timber houses. In part this could be rationalised as a lingering sense of nostalgia that might favour traditional forms of housing and the recognition that they suit the local culture and climate. However any sense of nostalgia must be countered with direct and persistent claims by a number of respondents that masonry houses perform less well than the timber varieties.

A pilot research project was initiated to test the claim that timber houses respond to the tropical climate more effectively by maintaining lower internal temperatures that the masonry alternatives. A series of four comparative tests were undertaken where temperatures were logged in both masonry and timber houses. Figure 3 and Figure 4 show two of the four tests and compare temperatures inside typical timber houses with typical masonry houses. The remaining two tests share similar profiles to those in Figure 3 and Figure 4. Figure 3 is based on two houses in northern Thailand while Figure 4 is based on two houses in northeastern Thailand. The timber houses were constructed with walls made from twelve millimetre thick hardwood timber planks and these planks had aged to a deep grey/brown colour. The masonry houses had walls of standard one hundred millimetre concrete block and a white paint finish. None of the rooms were air-conditioned and all relied solely on cross-ventilation and electric fans for cooling. All rooms were well cross-ventilation with similar sized open windows on two opposing sides of the room. All windows remained open during the period when the measurements were taken. The rooms were similar in size – approximately 6 x 6 metres square.

The internal temperature measurements were recorded at five-minute intervals over a three-day period in early July (Figure 3) or early September (Figure 4) using two 'Tinytag' temperature recorders – one in each of the houses. Outdoor measurements were not recorded due to the limited number of temperature recorders and the primary aim to compare the interior temperatures of both timber and masonry houses. For Figure 3 the recording devices were located in the southeastern corners of the room one metre from the floor and half a metre from the walls. Both rooms had two occupants during the night and so produced comparative live heating loads. For Figure 4 the recording devices were located in the center of the room two metres from the floor. The masonry house had two occupants while the timber house had four occupants. The shaded section of Figure 4 records a period of unseasonally heavy rain and the recorded temperatures are expected to be lower than average as a result. As a general rule in the tropics there are many months around April where the maximum daily average is 36 degrees celcius (minimum 25) while December has the maximum daily average of 29 degrees celcius (minimum 22). The periods tested in this project offered the opportunity to measure months with median temperatures.

![Figure 3: A comparison of temperatures inside typical northern Thai masonry and timber houses](image)

Figure 3 and Figure 4 reveal the differences between the internal temperatures inside both masonry and timber houses in northern and northeastern Thailand. They show that masonry houses are hotter than timber houses throughout both the day and night. The difference is greater during the evening and at night as opposed to the period during the morning. This is the period when the residents of timber houses experience the greatest benefits over those in masonry houses and comes during the time when they are likely to be inside the house rather than the period when they are at work outside the house. Correspondingly the most disadvantageous time to be inside a masonry house is when the resident is inside during the evening or at night when they are asleep. Figure 3 shows that on average timber houses are between 2 to 2.5 degrees celcius cooler in the hours between 6pm and 6am, when they are most heavily occupied, and one degree cooler between 6am and 6pm. The difference is anticipated to be proportionally lower during the cooler months and proportionally higher during the hotter months.
Broadly speaking these results follow patterns outlined by Anderson in the seminal text *Solar Energy: Fundamentals in Building Design* (Anderson 1977). Anderson (Fig. 5) plots the temperatures inside both lightweight and mass buildings against time and reveals temperature gradients fluctuating according to time. Temperatures inside lightweight buildings are sometimes higher than temperatures inside mass buildings and his rationale is that lightweight buildings respond more rapidly to changes in outdoor temperatures while mass buildings tend to maintain their temperature over a longer period of time. The more even temperature profile generated within mass buildings is because thermal mass and ground coupling provide both dampening and time-lag effects which reduce the amplitude of the temperature variations and delay their effects by several hours.

Comparisons between the two studies are revealing and the usefulness of this study is that it demonstrates some clear differences to Anderson’s model. In particular it calls into question the assertion that there are periods of the day when temperatures inside lightweight buildings are higher than temperatures inside mass buildings. The author’s results show that lightweight (timber) houses always remain cooler than the mass (masonry) houses. The difference between these results could be explained by the locations of these two studies. Anderson’s study is in North America – a temperate zone that has high differentiation between seasons, high differentiation between daytime and night-time temperatures and consequently high diurnal swings. By contrast the author’s study is in the tropics where seasonal differences are less significant, average maximum daily outdoor air temperatures are 33 degrees celsius, temperatures rarely dip below 25 degrees celsius during the night and where diurnal swings are low. It is possible that the consistently high temperatures in tropical zones affects the performance of the construction materials – for example consistently high temperatures do not allow the mass buildings to cool down enough to enable internal
temperatures to reduce to the comparable levels of the lightweight alternatives. A more extensive comparative study will be undertaken in the near future to test this hypothesis.

Another relevant study Effect of Envelope Colour and Thermal Mass on Indoor Temperatures in Hot Humid Climate suggests that building orientation, colour and construction materials combine to affect thermal performance (Cheng et al 2005). Their methodology utilised a series of cubic test ‘cells’ – with sides up to 1.5 metres – raised 0.8 metres from the roof of a seven-storey building at the Chinese University of Hong Kong. The walls of their test cells were made from composite panels of 20mm plywood and 25mm Styrofoam interior thermal insulation. Their first experiment tested the effect of envelope colour on internal air temperature. Results showed that the maximum air temperatures inside the white painted cell were 12 degrees celsius lower than in the black painted cell but differences in minimum temperatures (during night time) were negligible. Hence the darker the colour the higher the potential maximum internal temperature and the higher the diurnal swings. Their second experiment is more useful to this research project in that it compared results when another layer was introduced to the composite panels forming the test cell – in effect further insulating the cell. The third layer was formed from 90mm thick concrete brick and turned the test cell into a ‘mass’ walled structure. As expected two significant points are worth noting, firstly the added thermal mass had the effect of further suppressing the diurnal swing as compared with the lightweight cell – there were lower maximum temperatures and higher minimum temperatures – and the diurnal swing was halved. Secondly the peak temperature in the mass cell was delayed by four hours which enabled periods of time in the morning when the temperature inside the mass cell would be lower than in a lightweight cell. This would allow a temperature/time profile to be plotted where it would be possible for periods of the day to be cooler inside a mass building.

Results of the current project appear to contradict the results of the two published research projects. Aside from the inevitable errors that come from the author’s methodology (principally the difficulty of comparing a series of houses identical in every way aside from being constructed from either lightweight or mass materials) there are various combinations of factors that could drive these differences. Firstly there is no clear case why Anderson’s results must be directly applicable to a study of temperature/time profiles in various house types in tropical locations. Secondly Anderson’s results were generated in North America where high diurnal swings are the norm as compared with the author’s results obtained in northern and northeastern Thailand where lower diurnal swings are the norm. Given the lower diurnal swings in tropical regions it would appear likely that the capacity for houses to dissipate heat during the night is significantly diminished and higher heat loads are likely to be maintained over a longer period of time.

Thirdly Cheng’s results (and possibly Anderson’s) do not take into account the link between technology and house form – they are theoretical models rather than ‘actual’ models. By contrast the author’s measurements were taken with actual houses and so reflect the role played by the style of the housing. Lightweight houses are raised off the ground on stilts with the living/sleeping spaces – and temperature measurements – taken at first floor level. By contrast the mass houses are built with the slab directly on the ground as it is technically difficult, and particularly expensive, to build mass houses on stilts. Therefore lightweight and mass houses have different typologies and the role their style plays on thermal performance is important. This is particularly relevant as masonry houses have a stronger connection to the earth and less capacity to dissipate heat to the air. Alternatively timber houses are raised high on stilts, have increased air-flow around and under the house (improved cross-ventilation) and consequently have greater capacity to shed their heat to the air. This leads onto one of the limitations of Cheng’s methodology where the mass cell was raised 0.8 metres from the ground. In a ‘real-life’ situation this structural system would be impractical and the claimed benefits of mass construction are likely to be somewhat diminished as the amount of air-flow would be diminished. Finally Cheng’s results were based on a closed system – the 400mm x 400mm openings built into the opposing sides of the cells were not open during their experiment. It is highly likely that the time lag effects recorded would not be so significant if this closed system was opened or once the effects of any cross-ventilation were included.

While theoretical models have their place it is also important to test actual situations even if all variables cannot be fully controlled. In this case the value of Anderson and Cheng’s results as a determinant of real-life conditions in tropical locations can be called into question – particularly the notion that thermal mass might be used to deliver higher levels of thermal comfort.

3. THE LIGHTWEIGHT ALTERNATIVE

The previous section makes the case that lightweight construction materials are better suited to tropical climates than mass materials as they can be used to maintain lower internal temperatures. Figure 3 revealed that they remain between 2 and 2.5 degrees celsius cooler during the evening and night – the key period when the houses are being used. However timber is no longer available as a contemporary lightweight construction material because of the effects of deforestation and that there has been no attempt to formulate sustainable forestry industries. This paper is part of a larger project making the claim that fibre-cement planks or panels are a suitable alternate construction material to timber and masonry. There are five areas where the advantages are particularly strong.

3.1. Physical properties

Fibre-cement panels have similar thermal properties and physical characteristics to timber boards. Both are lightweight materials that can be cut into planks or formed into panels and used as a cladding material. As such it can work in the same way as timber and can retain the same appearance – even to the extent that a faux timber grain can be imprinted on the face of the plank. Alternatively it can be installed in panels detailed to resemble masonry and so connect with the same levels of status associated with masonry. As it is a lightweight product it enables houses to be built on stilts with an open-air undercroft below – hence its use is not as restricted as masonry technologies and it
can replicate the form and design principles that have driven South-East Asia’s traditional architecture over many
generations.

3.2. A ‘kit of parts’
Just as the traditional timber house was made from a series of prefabricated pieces and could be assembled (and
dismantled) so too could a house made from panels or planks formed from fibre-cement. A ‘kit of parts’, with modular
components specifically designed to fit together, could be put into production. The installation of the components
could occur incrementally with families purchasing prefabricated pieces for the walls, floors and roof and then
connecting these to a specially designed frame. The frame could be formed from reinforced concrete – the system
commonly used to frame the masonry buildings common in the region – or it could be built from steel if the budget
allowed. Doors, windows, and internal fittings could be added as required and the size of the house could expand as
the family’s economic resources permitted. Various options could be available to suit various prototype plans –
allowing houses to be personalised and tailored to suit the family’s needs. This system, reminiscent of the model
discussed by Habraken (1972), should be so simple that specialist contractors would be used sparingly.

As a technical system this kit of parts fits somewhere between the mass-produced model and the low-technology,
owner built model. It would take advantage of the economies of scale that come with modern manufacturing systems
and offers the enhanced levels of status that accompany consumer goods. The reinforced concrete frame, to which
the fibre-cement panels are attached, is the same technology currently being used to frame masonry houses and is
familiar to the client. At the same time the system reflects traditional lightweight and modular construction methods
with prefabricated componentry.

3.3. Low embodied energy
Table 1 compares the embodied energy required to manufacture three common building materials. Embodied energy
is the energy consumed by all the processes associated with the production and delivery of a building material. The
table compares panels of fibre-cement against the two most common masonry construction materials – concrete
block and clay brick. What it reveals is that concrete block and clay bricks have embodied energy figures that are
respectively one third and one half the figures of fibre-cement when calculated per kilogram. However these materials
are all used to form walls of different thickness and weight. When wall thickness, weight and the coverage of the wall
in square metres are calculated a different picture emerges. The amount of embodied energy required to construct
fibre-cement panels is approximately five times less than concrete block and ten times less than clay brick when
calculated per square metre of wall. This efficiency is significant and makes fibre-cement walling a key alternative
material with both better thermal performance and less energy required in production over its two main rivals –
concrete block and clay brick.

Table 1: A comparison of the embodied energy associated with three common construction materials

<table>
<thead>
<tr>
<th>Commonly Available Construction Materials</th>
<th>Embodied Energy MJ/kg</th>
<th>Embodied Energy MJ/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete block</td>
<td>1.5</td>
<td>270.61</td>
</tr>
<tr>
<td>Clay brick</td>
<td>2.5</td>
<td>551.49</td>
</tr>
<tr>
<td>Fibre-cement panels</td>
<td>4.8</td>
<td>54.72</td>
</tr>
</tbody>
</table>

Source: (Author 2005)

3.4. Some existing market awareness
Fibre-cement panels already have some application in South-East Asia and limited market share. However there is a
common perception that the product fractures easily. Knocks that would be insignificant in quality panels often
fracture locally made panels. As the quality of locally manufactured panels has traditionally been considered poor it
has generally been used in applications with minimal chance for impact. Hence it is used to line ceilings, the eaves
under roof overhangs and gable ends. It is a common sight to see fractured panels in commercial applications and it
is easy to understand why people would be reluctant to use it for housing. However local manufacturers have
recently improved their product with new manufacturing processes that have brought the panels and planks in line
with international standards. The key task for local and international companies will be to convince potential users
that the product is more versatile than it once was and that its performance will exceed their expectations.

3.5. Passive cooling
To cope with high heat loads there is a trend in tropical regions to use air-conditioning technologies inside masonry
houses. This is as much an ideological need as it is a physical need as the wealthiest sectors of society follow
patterns of consumption common in developed nations. However there are significant problems with this strategy.
Firstly the poor cannot afford both the initial outlay required to purchase the air-conditioning unit, let alone the
continued running costs. Secondly air-conditioners consume large amounts of electrical energy and contribute to
greenhouse gases. This use of air-conditioning is a short-term solution to a long-term problem and the development
of alternate housing systems that reference passive cooling ideologies is a key priority to reduce energy
consumption. Success will require excellent design strategies with particular attention paid to components that enable
the house to cross-ventilate as this is the most effective way to cool a house on a tight budget. In this regard
reference needs to be made to the design of traditional timber houses – the slatted walls, gaps between wall planks,
open planning, interior screens rather than fixed walls and open planning. These traditional technological patterns
have worked well in the past and must be carefully studied and reinterpreted with the new materials.
CONCLUSION

This paper argues that the resident’s claims that mass houses are less thermally comfortable than lightweight houses in tropical conditions may well be valid. Although academic studies have produced results that indicate mass structures have lower internal temperatures than lightweight structures for some periods of the day this project has shown that there is evidence that this might not be the case in all applications. A series of tests undertaken in ‘real-life’ conditions in tropical climates has demonstrated that the thermal advantages connected with mass construction may well be exaggerated. The evidence suggests that a lightweight house are cooler throughout the day and more than two degrees celsius cooler during the parts of the day when the houses are most likely to be occupied. It is suggested that mass walls do not thermally ‘work’ in the same way as lightweight walls due to their contact with the ground and their correspondingly diminished capacity to shed heat. In effect the mass house is never able to effectively cool down to the same extent as the lightweight house.

The limited access to traditional construction materials, coupled with the aspirations for modern housing types, requires the introduction of new construction systems in tropical climates. Fibre-cement panels and planks could form the basis of this system – they share similar physical properties to traditional systems whilst still affording higher levels of status, they use a similar ‘kit of parts’, have lower embodied energy requirements, have some existing market awareness and can take advantage of design strategies that encompass passive cooling techniques.

REFERENCES