Reducing the energy use and the carbon footprint of tropical housing

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Abstract

Following some decades of effort to reduce the energy embodied in, or consumed in, temperate housing, focus is now shifting to a similar effort for tropical housing. Energy reduction is a well-established strategy for reducing GHG emissions. A research consortium 'ELITH' of six-partners (of whom two are East Asian) has been funded by the UK government to investigate how the energy use, carbon footprint and cost of 'low-income' tropical housing might best be reduced. The research combines engineering, building science, architecture, town planning and physical modelling. Examples of programme research topics are (i) examination of the relationship between 'active' and 'passive' cooling under humid tropical conditions and (ii) how to reduce the energy embodied in walling. This paper focusses on the latter.

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1. Introduction

There is global concern about over-usage of fossil fuels and the associated threat to climate stability. Energy consumption in the lifetime of a house takes two main forms: 'embodied energy', mostly consumed before and during the building's construction, and 'operational energy' consumed during its subsequent life. Both are affected by building design. Since 1980 there has been a massive effort in temperate countries to reduce housing's operational energy by minimising winter heating needs. This has entailed better thermal design, new materials, more efficient heating devices and stricter building regulations. Following these reductions in operational energy focus has begun to switch to reducing embodied energy and any associated greenhouse gas generation (GHG).

Indicative figures for both temperate and warm climates show that over one third of national energy use is in the building sector. In new low-energy buildings, where the operational energy has been much reduced, embodied energy accounts for over 25% of the total energy and climatic footprint.

The design of tropical housing has to date been little affected by the energy agenda. However in hot climates there is urbanisation with its 'heat island' problems, growing demand for air conditioning and a shift in heat-producing domestic activities from outdoors to indoors. These have justified starting a 5-country research programme entitled 'Energy and Low-income Tropical Housing' (ELITH) funded jointly by two UK ministries responsible for respectively climate change (DEE) and poverty reduction overseas (DFID). The programme addresses reducing operational energy in housing, reducing embodied energy and means of promoting reductions in both.

ELITH's research into operational energy of housing is focussed on East Asia. 'Monsoon' Asia has a climate of hot wet summers and warm winters. So unlike in a desert climate, there is little scope for night-time cooling by radiation to a cold sky, nor for any form of inter-seasonal storage of 'cold' from Winter to Summer. Achieving indoor thermal comfort is a major driver of ASEAN architectural design. However the expectation that this can be achieved *only* by universal adoption of intensive and costly domestic air-conditioning (AC = 'active cooling') is beginning to be challenged. 'Passive' cooling by good design of buildings and cities also has a role to play, by allowing AC systems to be down-sized and improving the comfort of households too poor for AC.

The ASEAN population prior to 1960 was overwhelmingly rural: traditional building designs and customs offered some relief from thermal stress. Domestic air conditioning was almost nowhere an option. Today most new homes are in urban areas and increasingly have AC; the social usage of housing has changed. Some traditional materials such as hardwood have become scarce, while others, such as sun-dried mud, are now considered to have too short a life and too poor a finish. Yet there is scope for carrying ideas from vernacular architecture into modern housing design and ELITH is exploring these.

Although some housing functions – such as providing adequate privacy and security – are not direct users of energy, there are household activities, such as cooking, laundry and entertainment that do. If performed indoors they also generate heat and add to thermal stress. It is therefore part of ELITH's strategy to minimise the energy demands of these activities by developing more energy-efficient devices and where possible relocating them out of doors.

Maintaining indoor comfort has traditionally consumed little energy in SE Asia, yet this 'comfort' aspect of housing now threatens to become the major domestic energy consumer. This threat affects household budgets, investment required for power supplies and to some degree national energy security. Indoor comfort is the outcome of a train of processes that link, in sequence, (a) regional climate, (b) urban climate (getting hotter), (c) the 'street' climate immediately outside a dwelling and (d) conditions inside the dwelling. The link from (b) to (c) is the focus of the urban design component of the ELITH programme, whereas the link from (c) to (d) is the focus of its research into architectural and building services options. It is the ambition of some European architects to reduce operational energy almost to zero (e.g. the 'Passivhaus' movement & International Passive House Association) – which is easier to achieve in cold climates than in hot humid ones. Reducing heat gains and 'passive' cooling are the main mechanisms to employ in SE Asia, where ELITH's research into passive cooling centres on achieving adequate indoor airspeeds.

Of growing concern is the increase, with urbanisation and global warming, of occasions when heat stress becomes lethal for some citizens. Inadequate passive cooling leads to increased demand for active cooling which itself adds to urban heat generation. Moreover during extreme heat waves it is unlikely that electrical power networks will have the capacity to supply all the installed air conditioning in a city. Thus public health as well as economy and climate care point towards reducing the energy used to achieve thermal comfort.

2. The 'Energy in Low-income Tropical Housing' (ELITH) research consortium.

The ELITH research team comprises 2 East Asian, 2 East African and 2 British partners. Three of the partners are represented in this SEE conference. Within the programme team are architects, a town planner, specialists in small-scale building enterprises and engineers. This paper continues with one example, namely lower-energy walling, of the research being undertaken. A separate paper (Cheshmezangi & Butters) deals with a second topic.

'Low-income' in the programme title has been taken to mean 'the poorer half of the population': the funders' objective is to make housing cheaper as well as 'greener'. The big differences in wealth and climate between E Asia and Africa (where only the richest 2-3% of households employ AC) mean there is limited scope for integrating Asian and African strategies and building designs. Reducing housing's operational energy is ELITH's priority in SE Asia. In East Africa, where operational energy is not yet high, ELITH is concentrating on how to reduce embodied energy.

3. Example : Reducing Energy Embodied in Walling

Walling has been chosen as a focus, as it accounts for much of the energy embodied in a newly constructed house. The decline, over the last 30 years, in the use of organic materials and of unstabilised soil for walling means that much of its energy now comes from fossil fuel or wood, (though in the decades ahead we can expect some replacement of fuels by renewable energy sources). Any embodied-energy strategy needs to look at how to reduce the *amount* (e.g. weight or volume of material) per square meter of walling, how to reduce the *energy intensity* of the material used and how to increase the longevity of walling. The specification of walling is meanwhile itself changing – for example towards less maintenance and higher insulation.

Longevity – for example a target life of 100 years – controls the translation of embodied construction energy (plus lifetime maintenance energy) into an annual equivalent. The rules for this 'translation' constitute a research topic in itself.

Walling, which forms the major mass in most new tropical buildings, should be:

Strong (against vertical & horizontal forces) and Hard (against erosion)
Stiff (resistant to buckling, of high natural frequency, serviceable)
Durable (proof against fire, flood, quake and rot, repairable and easy to modify)
Of low permeability to water, low conductivity to heat and sound
Attractive yet cheap (components and assembly) and lightweight

Masonry (bricks and blocks and only rarely stone) satisfies most of these requirements, except that it has poor tensile strength, is heavy and is slow to erect or modify. Unfortunately it embodies a lot of heat energy, which normally derives from the burning of fuels and emission of greenhouse gases. Typical 'embodied' energy figures are

Walling technique	**MJ of heat per m^3 of walling**
Unstabilised rammed earth, cob or wattle-and-daub	negligible
Crudely mortared 'country' bricks, 25mm rendered and 25mm plastered	3800
Well-mortared kiln-fired bricks, 20mm plastered, not externally rendered	2500
Hollow cement blocks (sand:cement = 4:1), 10mm mortared. 25mm plastered	1300
Unmortared, pressed, stabilised-soil blocks (soil:cement =14), 25mm plastered	700

However a wall's cost is not proportional to its embodied energy density: country bricks are cheap.

Bricks and blocks are often produced by inefficient processes without good quality control. This leads to high energy intensities, wastage rates as high as 8% and poor durability. Yet there are social reasons for trying to improve the localised artisanal manufacture of cheap bricks/blocks rather than simply encourage its replacement by large-scale industry. The height of housing is also rising (although rural housing in East Africa is still almost exclusively single-storey): some currently popular walling techniques are inadequate for 2-storey construction.

One walling option is to get rid of the energy-intensive 'mortar' that commonly bonds blocks together. Another option is to reduce the need for brick/block walls to be both plastered (internally) and cement-rendered (externally). A third is to reduce the average material-thickness of walls – yet retain their stiffness. The ELITH programme component on reducing embodied energy has started with examining these options in an African context.

As mortar performs many functions, these need other means of achievement if mortaring is to be avoided. The mortarless techniques being researched include:

- Modifying brick-laying techniques and brick shapes to achieve vertically-straighter walls
- Using interlocking bricks, able to resist 'punch-through' forces yet entailing few geometric constraints on wall design.

- Restoring, by such means as employing zig-zag, crenelated, sinuous or buttressed wall plans, the wall stiffness massively sacrificed by omitting mortar
- Sealing the gaps between courses by fine pointing or mortar injection after construction.
- Increasing effective wall thickness without increasing wall mass (e.g. by increasing the hollowness of brickwork).
- In seismic zones using fibre-reinforced renders in a sandwich about thin weak walling.

Tanzanian House made of Mortarless Interlocking Blocks of Stabilised Soil

A second strand of walling research is examining how the clamp-firing of 'country bricks' can consume less firewood, and how their geometric and mechanical properties can be improve.

A third strand concerns the use of compressed stabilised-soil (CSS) as a substitute for fired brick in load-bearing walling. The fraction of energy-intensive stabiliser in CSS can be reduced by better soil selection, higher pressure moulding (up to 10 MPa) and better quality control. Changes in architecture can permit thinner walls. These are being explored via experimentation in Uganda and Tanzania.

4. Propagation

Propagation of ELITH research findings – via demonstrations and the training of builders, architects and brick-makers – which will start in 2015, will be difficult. Few of the energy-research findings of recent years have succeeded in modifying house-building practices and designs in Africa or Asia.

5. References

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