The University of Warwick

A PASSIVE COOLING RETROFIT FOR LOW COST, HOT CLIMATE HOUSING

Chris Butters

School of Engineering, University of Warwick, UK

This Paper addresses operational energy and indoor comfort with particular focus on simple retrofit solutions for low-cost housing in developing countries. Technical innovations may eventually "trickle down" to the poor, though that notion is often queried, but in the meantime, millions continue to live in extremely bad conditions. Relatively simple measures could make a large difference to their indoor environment, health and wellbeing. One such measure is discussed here, in a new variation on a retrofit concept that was discussed and tested some years ago by one of the pioneers of passive climatisation in buildings, Baruch Givoni (Givoni 2011). A simple retrofit solution is described in order to reduce the internal heat gain caused by the uninsulated metal and similar roofs that are typical of low income buildings.
The EPSRC-funded ELITH program (1)*, with lead partner Warwick University, UK, concluded in mid-2016. This research proposal was considered of particular relevance for our two African partner countries, Uganda and Tanzania, where large rural and peri-urban populations live in such dwellings. The proposal remains to be tested and evaluated in the field.*

Background

The overall objective of the ELITH program has been to research and promote sustainable solutions for low cost housing in hot climate developing countries, whilst minimising energy use and climate emissions. Passive, i.e. non-mechanised solutions are in this regard a priority since they "design with nature" and avoid the need for fossil fuels or other bought energy. Good, climate-adapted design can reduce the need for added technology to a minimum. In addition, passive solutions can be cheaper and, being non-mechanical, are robust with regard to users, operation and maintenance.

Experts in the field of climate responsive design including Dr. Givoni have often referred to solutions that date back 20 or 30 years but have seldom if ever been fully tested or applied. Whereas much research funding is directed towards technical innovation, there is a greater need for effective *delivery* of what are often well proven, and not least cheap, solutions for more sustainable building. The primary goal of such design, as formulated in our GAIA group (ref GAIA), is *buildings that are healthy for people and for the planet*. In other words, quality of life combined with low ecological footprint. This is the real goal of sustainable buildings, for it combines human health and comfort with the ecological goals of minimal operational and embodied energy use and climate emissions.

Millions of low-income dwellings have roofing of corrugated iron (CGI) sheeting, which causes extremely uncomfortable indoor conditions both in summer and in winter. Solutions to improve this must be extremely cheap since these population groups have the lowest if any significant incomes. Many more dwellings as well as schools, offices and other buildings in developing countries have similar uninsulated roofing. In many cases these buildings are being or are in future likely to be provided with space cooling, causing rising energy use and climate emissions. High-end technological research seldom addresses the needs of the lowest income users who also experience the worst indoor comfort and health conditions.

Typical rural house construction, Tanzania (source: Amri Juma)

Typical slum housing with CGI roofing, Capetown, South Africa (source: author).

SIMPLE RETROFIT FOR LOW INCOME DWELLINGS

Several promising concepts may be explored. Described here is a simple retrofit to existing buildings which have a metal roof such as corrugated galvanised iron. The proposal primarily addresses single storey buildings and the upper floor of multi-floor buildings. Our main focus is hot country conditions but the proposal is of relevance for cold climates too, and for temperate climates where there is both a winter heating need as well as a summer cooling need. Other low-cost, uninsulated roof types with cement or sheeting are prone to the same thermal weaknesses and are relevant too.

The *technological level* is deliberately simple, in order to make such solutions applicable in very low income contexts, potentially on a self-help basis. More advanced variants are also noted briefly.

It is well documented that such buildings quickly overheat in hot conditions, primarily due to high solar incidence, and also become very cold due to rapid heat loss in winter and through radiation to the night sky. The proposal involves providing a simply mounted, movable interior ceiling layer that insulates against unwanted heat loss or gain. A previous proposal developed in the USA was for lightweight panels hinged to the ceiling that can be raised or lowered according to needs in the day or at night. Such panels could consist of lightweight insulation such as EPS, which however presents a fire hazard, or of reflective foil mounted on light frames. As simply put by Givoni (Givoni 1994):

Interior insulation plates are not exposed to the wind and the rain and thus can be simpler in construction, lighter, and much less expensive than external insulation panels. The changes in their position, vertical, or horizontal, can be controlled from the interior manually

This solution was tested at UCLA in two tests, by Gulish (Gulish et al 1996), and later by la Roche and Givoni (Givoni 1998), in different buildings containing less or more thermal mass. The impressive effect in moderating indoor temperatures is shown in (fig.4.3, from Givoni 2011) for the high thermal mass case - indoor temperatures being lowered by fully 10 degrees. One may add that thermal mass will be most important in hot-dry regions with significant diurnal swings, whilst mass can have somewhat differing and more complex implications in hot-humid climates, see for example (Chirarattananon et al 2011).

Other solutions to ameliorate indoor conditions in hot climates include the simple remedy of painting roofs with white reflective paint, which lowers indoor temperatures by several degrees; this applies both to CGI and to flat concrete roofs which are common in many countries now; green (planted) roofs, an effective but quite expensive option: and alternative roofing materials such as microconcrete roof tiles, which although relatively expensive can still be far cheaper than CGI sheeting, in addition to being climatically much better.

The World Bank “Cool Roofs” program. Painting concrete roofs white to reduce indoor temperatures – India. Source: www.cleanenergyministerial.org/GSEP

Microconcrete (MCR) roof tiles produced on site cheaper than CGI sheets; here also with a ventilated roof. Low cost houses, Bhutan, architect Chris Butters (source: author).

A PROPOSED NEW VARIANT

Whilst cheap and effective, a disadvantage of the above solution is that the panels when opened can conflict with furniture, doorways, high window openings, lighting and other ceiling or wall mounted interior fittings. It may be noted that a similar generic problem complicates the design of movable *exterior* insulating devices.

In both hot and cold climates reflective foil is sometimes used, spread in attics, for the same purpose. A disadvantage of this is that it hinders use of the attic space, and may also become ineffective due to dust. Being in place permanently it may also form an unwanted vapour barrier in some cases.

By instead using a layer of reflective insulation that can be *rolled* open or closed, this disadvantage can be overcome. The only residual potential space conflict is then with ceiling mounted installations – lights or fans. Ceiling lights, which in very low cost housing are most likely mounted with simple open cabling, can easily be relocated to walls. Failing this, or in the case of fixed ceiling fans, the ceiling insulation can be mounted in sections running one on each side of the ceiling light or fan.

This insulating layer should be mounted a few centimetres below ceiling level, with provision of some simple vents at wall-top or roof edge in order to release accumulating hot air. This would add an element of passive ventilation cooling. The effect of such a ceiling retrofit must be considered *in comparison to or in combination with* other passive strategies such as exterior roof shading or reflective colouring. This is important since *the relative effect* of various passive cooling strategies and building elements has seldom been elucidated. (Butters, ELITH 2015).

This solution, similar to roller blinds, most but not all of which are designed to operate vertically, can be operated by simple pulleys with strings or cables mounted on existheting walls or ceilings. It is robust in practice for the following reasons –

- exact fit or air tightness is not critical
- minor damages can be repaired simply by sewing or even with tape
- simple pulley mechanisms are easy to maintain and repair
- operation is user-controlled, simple, and needs no mechanical energy.

This type of solution is much cheaper than constructing a conventional ceiling with a ventilated air space above, which in addition to higher room height requires as a minimum a structure of battens and plywood or similar panels.

The proposal is most applicable in hot-dry climates with high insolation where there are diurnal temperature variations and where thermal mass may provide advantages. It is of interest for hot-humid contexts too although solar incidence is sometimes more diffuse and high ambient air temperatures both indoors and outdoors (as well as high RF) play a deciding role.

HIGH END APPLICATIONS

In terms of cost, design and aesthetics there are many options ranging from simple loose-fit rolls of insulating foil to smart textiles with attractive patterns. A useful commercial comparison is to be found in typical German *rulladen* of recent years, developed as external insulating window blinds, as well as in many architecturally popular external shading screens, often mounted on slim and elegant metal cables. Typical well designed *rulladen* are neat and tight fitting with cables concealed within the lateral fixtures. Some variants have thicker, insulating textiles.

This solution is also applicable to buildings with other, uninsulated roof materials. Sophisticated versions with motor drive or even automated with a climate control program can be considered too. Our main interest here however is in lowest cost applications.

Typical German exterior "rulladen" blinds. Source: author.

Exterior façade blinds combined with PCM (phase change) salts, Zurich. Source: author.

Common vertical pulley fixture. Simpler models are common and can function horizontally as well. Source: author.

DISCUSSION AND IMPACTS

Assuming similar values for temperature attenuation as in the abovementioned and similar studies, considerable comfort improvements can be achieved. The potential energy savings can be estimated too, though the starting point for this study is low-income sectors who are normally below the threshold of affording energy for space cooling. We are however, looking at potentially very large *avoided future* energy and climate impacts – assuming that the low-income sectors gradually gain access to energy services, including cooling; this is already a major trend in upward moving sectors.

Within the framework and time constraints of the ELITH program it has not been possible to carry out a field study and testing. One may nevertheless on a very preliminary basis evaluate potential energy avoidance in the case of a) fan cooling and b) conventional air conditioning (ref Est 2014). The cooling load for a typical 40 sq m dwelling in the tropical climate of Thailand for example is around 1,500 kWh per year (KMUTT/ELITH 2016). Reduction by this means of cooling energy needs of approximately 20-30% can be achieved in addition to the health and wellbeing benefits.

A simple pilot study would include estimation of the materials cost of installation in a typical small low-income dwelling of 40 sq m. The labour input would be of the order of 10-15 hours. In many developing countries, small scale tailoring workshops are plentiful, so that rolls can easily be made to measure. Total costs can therefore be very low.

Taking a ball park guesstimate of some 150 million homes of this type in hot developing countries, including the top floors of multi-storey buildings, this indicates a potential avoided energy use in the region of 120 TWh per year, or 100 to 200 Gt of carbon – equal to around half the present total emissions of the UK.

The health and comfort benefits are perhaps more important than the environmental ones. This is even more so when one considers that the lowest income groups will be unable to afford cooling, passive or active, for many years to come. Unless cheap and simple solutions are disseminated very actively, their energy and climate footprint will continue to be low, and their health conditions will remain as poor as they are today. The cost savings *in health terms* of achieving 3-6 degrees more comfortable indoor temperatures would also amount to a very large figure, even accepting the more open nature of such cost estimates.

CONCLUSIONS

Retrofitting with external insulation or ventilated roofs is expensive. Alternatives to reduce overheating of metal roofs by simple and cheap means are few. They include covering the roof with dry vegetation or other matter to hinder solar exposure, painting with reflective colours, and shading with trees – this latter often not easily achievable in slum contexts; and not possible at all for buildings of several storeys. In addition, such measures do not improve the winter situation where uninsulated roofs provide cold conditions.

Effective dissemination is our major concern. Low cost solutions should be easy for unskilled people and users to install, operate and maintain. If they are effective, then pilot and demonstration projects should lead to wide dissemination. This could be promoted by workshops to train local small-scale entrepreneurs or community groups. In situations where there are national housing agencies or social housing organisations, larger scale programs could be implemented.

As a general conclusion, the effectiveness, low cost and easy implementation of such solutions invites reflection on current research and development aid priorities. There seems little point in advanced technical research and innovation, when we are not effectively disseminating and delivering easy solutions, to those who are in most need of them, and with large potential savings as regards future energy and climate emissions.

…………………………….

ACKNOWLEDGEMENT

The Energy and Low-Income Tropical Housing Project ELITH is co-funded by the UK Department for International Development (DFID), the Engineering & Physical Science Research Council (EPSRC) and the Department for Energy & Climate Change (DECC), for the benefit of developing countries. Views expressed are not necessarily those of DFID, EPSRC or DECC. Grant number: EPSRC EP/L002604/1.

REFERENCES

(only a few references are given here)

Givoni, Baruch, some titles:
-*Man, Climate and Architecture* (1971, Elsevier Publishing Co., London.
-*Guidelines for Urban Design in Different Climates* (1989), World Meteorological Organization, WMO/TD No-346, Geneva-
-*Passive and Low Energy Cooling of Buildings* (1994), Van Nostrand Reinhold, New York.
-*Climate Considerations in Building and Urban Design* (1998), Wiley & Sons, New York.
-*Indoor temperature reduction by passive cooling systems*. Solar Energy 85 (2011) 1692–1726

P. Berdahl, S.E. Bretz, *Preliminary survey of the solar reflectance of cool roofing materials*, Energy and Buildings 25 (1997) 149–158.

Butters, C. *Enhancing air movement by passive means in hot climates*, ELITH Working Paper 05, Warwick University, May 2015.

Chan, H.-Y., S.B. Riffat, and J. Zhu, *Review of passive solar heating and cooling technologies.* Renewable and Sustainable Energy Reviews, 2010. 14(2): p. 781-789.

Chirarattananon, S., Vu Duc Hien, *Thermal performance and cost effectiveness of massive walls under Thai climate*. Energy and Buildings 43 (2011) 1655–1662.

Est 2014. *Impact estimates for cooling energy and carbon* / internal ELITH notes, KMUTT/Warwick.

GAIA group, sustainable architecture and planning, see www.gaiaarkitekter.no, www.gaiagroup.org, www. Gaiaecotecture. Ir ...

Gulish, M., Gomez, C., Givoni, B., 1996. *Radiant cooling by metal roofs for developing countries*. In: Proceedings of the 21st National Passive Solar Conference, Asheville, NC, April 1996.

C.Y. Jim, S.W. Tsang, Hong Kong, *Ecological energetics of tropical intensive green roof*, Energy and Buildings 43 (2011) 2696–2704 –

McHarg, Ian. *Design with Nature*. 25th Anniversary Edition, Wiley 1995.

Olgyay, V. *Design with Climate, Bioclimatic Approach to Architectural Regionalism*. New and expanded edition, Princeton 2015.

Santamouris, M., et al., *Recent progress on passive cooling techniques: Advanced technological developments to improve survivability levels in low-income households.* Energy and Buildings, 2007. 39(7): p. 859-866.

World Bank Cool Roofs program, India, see http://www.cleanenergyministerial.org/Resource-Center/Ministerials/CEM4-Resources/gsep-supports-cool-roof-pilot-project-on-low-income-housing-in-jasdan-india-10559

Many articles on passive cooling in *Energy and Buildings, Environment and Building, Building Research Information* and other journals.

……………………………….