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ENHANCING AIR MOVEMENT BY PASSIVE MEANS IN HOT CLIMATE BUILDINGS

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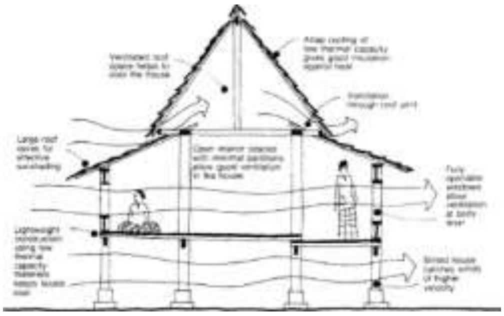
This paper describes investigation of and proposed research into applied design solutions for passive cooling in hot climates through enhanced air movement, with a particular focus on low income housing. The objective is improved living conditions whilst mitigating, as far as possible, energy use and climate emissions. The specific need is to achieve a comparative understanding of the relative technical efficacy, and cost effectiveness, of various design strategies and combinations of strategies for passive cooling. This comparative perspective appears to be significantly lacking in existing research and remains an IMPORTANT research task needing to be done.
The EPSRC-funded ELITH program, lead partner Warwick University, concluded in mid-2016.

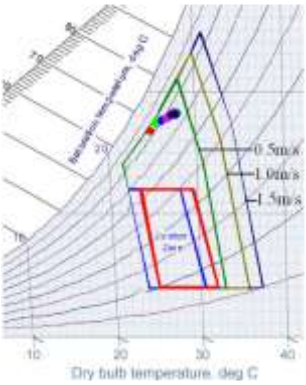
1. OBJECTIVES

The overall objective of the ELITH program (1) is 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 natural priority since they "design with nature" and avoid the need for fossil fuels or other bought energy. Good, climate-adapted design of buildings can reduce the need for added technology to a minimum. In addition, the passive solutions can be cheaper and, being non-mechanical, are robust with regard to users, operation and maintenance.

Air movement is a key to enhancing comfort in hot climates. In hot-dry climates, other passive strategies such as thermal mass and evaporative cooling are useful too. In hot-humid climates however, enhancing air movement is (in addition to solar protection) almost the only effective passive strategy towards comfortable indoor conditions, as opposed to air conditioning (AC) or other energy consuming solutions.



The Malay House, ill. Lim Jee Yuan:
Tropical vernacular climatic solutions: minimum solar exposure, maximum cross-ventilation, lightweight materials, open interior spaces



The psychrometric chart: how we can enhance Indoor comfort using air movement

Air conditioning is problematic for several reasons:
- It requires electricity, hence in most cases GHG-producing power generation,
- It is costly to operate, particularly for low income groups
- It increases the heat island effect in cities

- Some AC environments may contribute to less robust health

AC is spreading very rapidly. To avoid increasing energy use and GHG emissions it is important to prioritise alternative, passive strategies. For cost reasons this is even more the case for *low income* groups.

Passive design principles for hot climates are well known, not least from traditional architecture in many cultures. Methods of enhancing air movement are often found in vernacular solutions. Some are relatively well researched. Vernacular solutions often apply simple technical means, using excellent evergreen principles whose effectiveness may be improved by modern means. The *comparative* effects of passive design features have been less investigated however. There are also recent developments (mainly in industrialised countries) in the field of natural ventilation design, which have been little investigated for *low cost* housing.

2. AREAS OF INVESTIGATION

Low income housing in hot climate developing countries may be broadly defined in two categories. On the one hand, extremely simple housing such as one finds both in deprived rural areas and in urban slums or informal settlements. These population groups often have next to no energy amenities and very unhealthy living conditions, as well as a severe lack of public amenities. On the other hand, there are the millions who are moving to cities, often to high-rise and similar apartments of mediocre if not poor quality. It is in this new and generally upwardly mobile sector that energy amenities, as well as cars, are increasingly very rapidly and hence where there is major growth in global energy use and climate emissions. This is more widespread in our Asian partner countries China and Thailand, whereas the first category is more widespread in typical African countries such as our partners Uganda and Tanzania. However, both categories with their respective challenges are to be found in most developing countries.

Traditional buildings and town layouts in many cultures and climates illustrate excellent principles for adapting to local climate through passive design strategies; usually termed vernacular solutions, these contain many lessons for us. In hot climates, which are both of hot-dry and hot-humid type, space cooling is a key task for indoor comfort, and may be achieved in many ways. The two fundamental principles to achieve passive cooling are solar protection and maximum air movement.

In brief, the following – following the various scales of design, from urban level down to building details – are the main passive methods of enhancing indoor air flow.

1.Urban layout

In all fairly dense built environments, favourable topographic localisation, street orientation, building volumes and vegetation can all be designed so as to improve local microclimates, in particular to create cooling effects, maximise urban ventilation and reduce the urban heat island effect.

2.Building surrounds

Vegetation, shading, planted surfaces and water can reduce solar heating around buildings and ensure cooler air. Landscaping and adjacent structures can also be shaped to increase air movement towards and into buildings.

3.Built form

Long, thin buildings facilitate cross ventilation. Building angles and curves can be used to capture air from predominant wind directions. Roof shapes, including overhangs, as well as balconies, can enhance air movement in and out of buildings, as can the building's vertical cross-section. Buildings raised above ground enable cooling through the floor. Raised floors or cantilevers also create shaded space where cooler air may be obtained. Courtyards, "corridors" or buildings split into two wings may provide a cool air draw. Outdoor or semi-outdoor spaces can be designed for functions that produce unwanted internal heat loads such as kitchens and laundry areas.

4.External openings

Openings, especially in hot-humid climates, should be generous, in principle larger on the leeward side, and flexible. Diagonals are advantageous, as are top, bottom and corner openings, as are ventilated roofs and openings in floors raised above ground level. Various forms of ribs and wing walls at openings - vertical, horizontal or angled - can help to direct air flows towards openings. Good detail design of the openings and fenestration can enhance air movement.

5.Internal layout

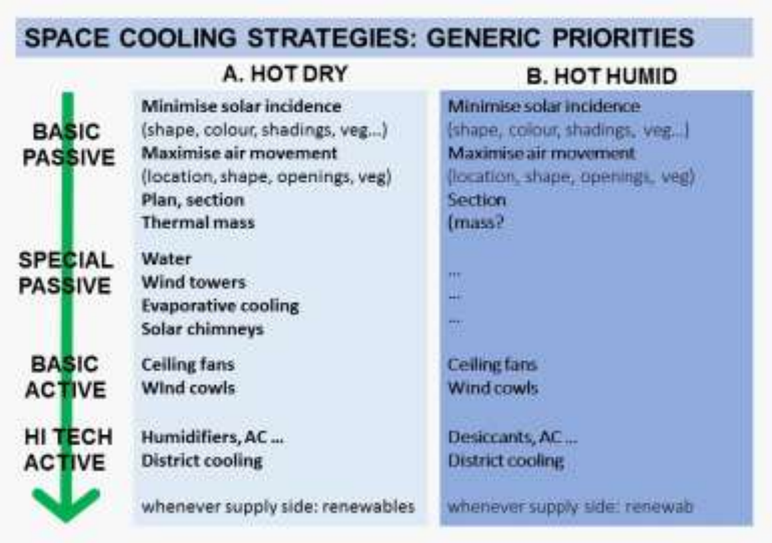
Internal walls as well as furnishings hinder cross ventilation. Hence it is best to have as open a floor plan as possible. Opening partitions or permeable constructions can be used; there is room for design innovations in this area. Traditional Japanese architecture provides a good example; though naturally, permeable partitions preclude acoustic insulation between rooms where this is needed.

6.Passive ventilation and stack effect.

Wind catchers, cowls, solar chimneys and similar devices enhance air movement into and/or extraction from buildings. Stack effect being proportional to stack size, this is in practice partly a cost issue. In multi-storey buildings stairwells can be used and, in larger buildings, atriums. However, stack effect is least when most needed (smallest pressure differences on hottest days). Stack effect is proportional to building height, hence somewhat less useful in low-rise low income buildings.

7.Fan assist

There is a "grey area" between active and passive strategies. In this context we choose to include very simple mechanical solutions such as ceiling fans (and simple roof mounted turbines), firstly since one often cannot ensure adequate comfort in the hottest climates with passive means alone; secondly because fans are robust, cheap, effective, universally available, and consume little energy.



SPACE COOLING STRATEGIES: GENERIC PRIORITIES

	A. HOT DRY	B. HOT HUMID
BASIC PASSIVE	Minimise solar incidence (shape, colour, shadings, veg...) Maximise air movement (location, shape, openings, veg) Plan, section Thermal mass	Minimise solar incidence (shape, colour, shadings, veg...) Maximise air movement (location, shape, openings, veg) Section (mass?
SPECIAL PASSIVE	Water Wind towers Evaporative cooling Solar chimneys	... ...
BASIC ACTIVE	Ceiling fans Wind cowls	Ceiling fans Wind cowls
HI TECH ACTIVE	Humidifiers, AC ... District cooling	Desiccants, AC ... District cooling
	whenever supply side: renewables	whenever supply side: renewab

There are more options available to designers for passive cooling in hot-dry climatic zones than in the hot-humid tropics (ill.: Butters)

3. EXISTING KNOWLEDGE AND RESEARCH

There is extensive literature on vernacular solutions, as well as a large body of more recent research into passive cooling designs and technologies. A broad literature survey suggests that although many of the above solutions have been investigated and applied in modern variants for buildings in higher cost brackets or in higher income countries, there has been less focus on low cost contexts. Research into natural and hybrid ventilation solutions, for example, has seen big advances in recent years, however most commonly applied for large offices and similar buildings.

Further, few researchers have investigated the *comparative*, or *cumulative*, effectiveness of different strategies. The effect of one specific cooling feature such as a solar chimney or a wing wall may reduce or even counteract the effect of others applied to the same building. One solution may be twice as effective as another in particular contexts. This is a key knowledge gap. Designers therefore lack guidance as to which strategies to prioritise. They may incorporate ones which are the most expensive, or even ones that have little more than cosmetic effect. It is popular to propose design features and "bioclimatic architecture" that appears to be environmentally favourable but may lack scientific justification.

In addition to investigating the *relative* functional efficacy of the various passive strategies, it is important to investigate how their *costs* compare both with each other, and to that of active cooling technologies. If, for example, active cooling can be provided using renewable energy, at a favourable cost, the supply-side approach may be preferable to the passive demand-side options.

Broadly speaking, existing research and publications fall into four categories:

- Serious “classics” of climate-responsive design and engineering - McHarg, Szokolay, Givoni, Olgyay and others (2), much of it dating back several decades, containing essential knowledge that has often been sadly overlooked,
- General handbook-type literature on ecological and passive design, including studies of vernacular solutions; these sources are often useful, but unspecific and lacking both in detail and in result-oriented documentation,
- Highly specialised scientific papers on particular themes of passive climatisation, such as solar chimneys, evaporative cooling, etc., often considering only one technique in isolation,
- Papers concerned with scientific methodology, measurement techniques, theory of heat transfer, CFD modelling, etc., some of which are also very theoretical and specialised in scope.

Available literature addresses both hot-dry and tropical climates, both industrialised as well as developing countries. There is a considerable body of research and expertise in Asia, including in our two partner countries China and Thailand; less in Africa where our two other partners Uganda and Tanzania are located.

As noted, amongst the scientific publications there appear to be few efforts to compare the *relative costs or relative effectiveness* of different passive solutions. A few brief examples.

A study of window configurations and cross-ventilation from Reunion found that “the comparison of the indoor air temperature shows a gap of more than 1.5 ◦C between the cross-ventilated dwelling and the other one” (3). But the question remains: in a building where one can open all windows and maximise cross ventilation, is it useful to *also* add other features, such as wing walls, or a stack effect chimney; or might those have *greater* effect that that of the openings?

Similarly, a study of reflective roof covering for solar protection notes that “the difference between the surface and ambient temperatures was as high as 50C with highly absorptive (low-albedo) dark roofs whereas the difference was as low as 10C with less absorptive light coloured surfaces” (4). But vegetation and green roofs are alternative strategies to the same effect. A Hong Kong study notes that “the woodland canopy could reduce 300Wm−2 energy flux into the substrate” (5). But is a green roof – expensive though having other advantageous qualities – more, or less, effective than high reflectance coverings? Which choice is best, and where?

A further question is whether passive strategies can provide conditions that are *acceptable* at peak hours or *in extreme conditions*. Many studies dating back to Szokolay and others (6) show that indoor air movement, normally best kept below around 1,0 m/s, can extend the comfort zone by around 3 degrees C. But air movement well above 1 m/s can be positive in extreme conditions, as suggested in another paper: *“*very intense at rates of 12500 and 18500 kg/h ... desirable only in high temperature conditions to reduce thermal discomfort*”* (7).

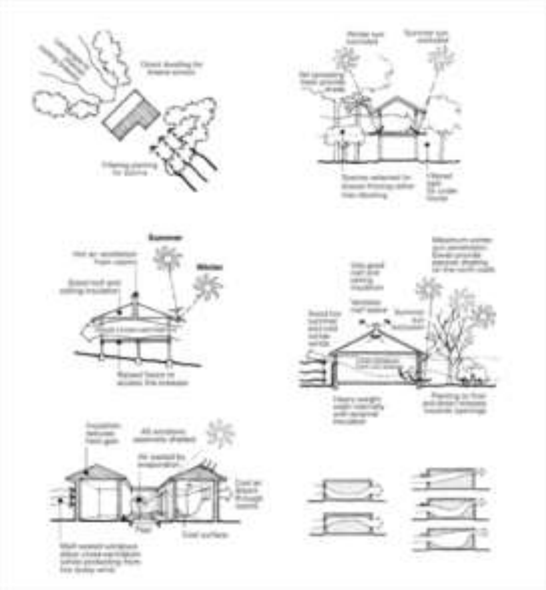
There appear to be few studies about potential benefits of moving functions such as washing and cooking facilities, which produce much unwanted internal heat, to semi-outdoor spaces such as covered verandas.

Many studies are theoretical and computational, with little reference to or feedback from applied solutions. In addition, the technical considerations alone are insufficient; it is well recognised that *non-technical* factors, including cultural and behavioural ones, often exert a profound influence and render theoretical studies somewhat irrelevant. This is emerging strongly in European post-occupancy experience with recent “passive” and low energy buildings (8, 9).

4. EXISTING HOUSING

Retrofitting of existing buildings is a large field. Several hundred million people live in very poor housing today, both peri-urban slums, poor quality urban apartment blocks, and in deprived rural areas. Most are likely to be there for a long time to come. Simple measures for very significant upgrading can, in addition, be inexpensive. The World Bank "Cool Roofs" project in India applied the extremely simple measure of painting the roofs of several thousand slum dwellings white, resulting in indoor temperatures being lowered by several degrees. This demonstrates an extremely simple and cost-effective approach which improves living conditions with no special cooling technology at all, nor indeed need for research! (10).

Enhanced stack effect ventilation: natural and hybrid ventilation is now used in an increasing number of modern projects. The Global Ecology Center, Stanford USA. (ill. Brianna Thompson)



Principles for maximising air movement

The challenges in the field of refurbishment are partly of a technical nature, but equally about effective *organisation, financing and delivery*. Processes should be participatory and "enabling" rather than top-down. In the case of our primary target, low income groups, a key goal is enhanced quality of life including comfort, health and security. These groups have very few amenities and consume extremely little energy and resources. In many cases, improvements will require somewhat *more* energy, technology, and costs; only in some may it also be able to offer *reductions* in energy consumption or climate emissions.

5. MODELLING AND FIELD STUDIES

The research discussed here is principally that of *building design*. The objective is to identify and promote solutions that are favourable in terms of cost and practicality. For example, wind chimneys are better if larger, but more expensive. Openings depend on user behaviour. Permeable or movable interior partitions may be effective but impractical due to factors such as noise, privacy and security. The ultimate goal is low-cost building design that eliminates the need for mechanised climatisation. Given a low-cost agenda, it is important to note that the objective is to identify, not ideal solutions, but *simple, cheap and practical* ones.

Work with housing involves engaging typical households over extended periods of time in order to test various simple physical improvement measures. Importantly, by working with existing settlements, *behavioural* measures can be included. In addition, the effectiveness of behavioural interventions could be compared with the effectiveness of purely physical ones. Surveys, refurbishment proposals, field tests and follow up can be based on existing buildings, containing real households. This would simultaneously be preparing a potential base for onward dissemination. Such a program would also offer avenues for involving schoolchildren and women; as well as useful "hands on" field work for researchers and students. The link between physical and social sciences offers another significant benefit.

Some of the above themes can be effectively studied by theoretical means and modelling. However, field investigation and testing is normally essential. A survey of research and best practice can determine which parameters can usefully be studied theoretically, which could use existing buildings, and which require a pilot facility and field tests. Solutions for enhanced air movement can be tested using relatively simple pilot buildings. Field measurements can be relatively simple. *Outdoor* conditions including temperature, humidity and air velocity need to be logged, however the "bottom line" is, simply, how much effect passive air movement measures can accomplish, in hot conditions, compared to a building without them.

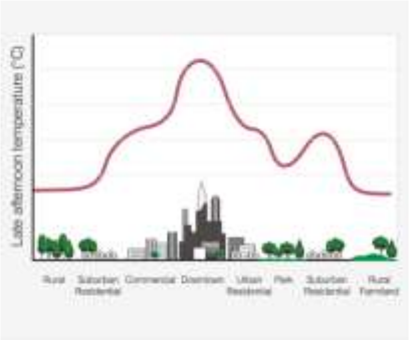
Logging *indoor* conditions can be onerous, but the measure of "success" is again, simply, reduced indoor temperature and increased air movement (plus arguably RH) compared to a base case. Measuring interior air velocity is important because it can provide a comfort effect corresponding to several degrees lower temperature; and to test which opening and partition configurations are most effective.

A test facility may be a simple structure composed of lightweight panels or heavier elements that can be easily rearranged to configure different openings, interior partitions, roof vents, overhangs and raised floors. In addition, lightweight mock-up additions can simulate exterior features such as awnings, breeze catchers and wing walls. This enables one to test both single strategies as well as synergic effects and to what extent a combination of several passive features could provide sufficient cooling to render added active technology unnecessary. Comparisons can thus be on three levels: with individual passive measures; with various combined passive measures; with and without fan assist. In view of the nature of the research question – only evaluating the *relative effect* on air movement of different strategies and configurations – the tests may be relatively simple.

For hot-dry climates, thermal mass needs to be considered too. The test facility should have a *generality* making it relevant for typical simple housing. One would primarily address relatively exposed locations, ranging from rural to quite open town streets; dense urban contexts are less favourable for passive ventilation both since air movement is often hampered, and since available air is often polluted.

Field testing and measurement is often complex and expensive. It may be noted - as a generic issue in energy research - that *detailed and exact* measurements are sometimes of limited value since non-technical factors such as common construction deficiencies, user behaviour or even interior furnishings may have effects of greater significance than marginal technical improvements.

There are at least two significant limiting conditions to applications of passive climatisation. Firstly, one must consider *extreme or "peak" conditions* and what response is appropriate when passive solutions (including fans) *are not* sufficient. The scenario is that of health threatening conditions, their intensity and frequency – especially in hot urban environments. Strategies may be technical or other. The solution of ensuring sufficient mechanical cooling equipment in every building is clearly expensive; and in practice *unattainable* in low income situations. Another not uncommon approach is civic/political; for example opening subways for homeless people on extremely hot nights (Paris) or providing emergency follow up services to elderly people during heat waves (UK?).



The Urban Heat Island: growing energy use, climate emissions, heat stress and mortality

Vanse School, Norway: natural ventilation (Bernoulli effect roof), GAIA architects

Secondly, in contexts where passive solutions are insufficient for *a significant part* of the year, users are likely to gravitate in future towards active solutions such as AC which provide full "cover" of comfort needs. But since the use of AC implies closing all apertures, this implies a flexible building design. To cater to this limitation, solutions must be sufficiently versatile to cater to *both* modes of operation.

6. PRIORITIES FOR PASSIVE COOLING?

There is a useful diagram in the USDOE guidelines for ventilation, where the very first question is: can the brief be solved with natural ventilation? If the answer is "no", one proceeds to mechanical solutions. The priority question, clearly stated, is to examine *passive design solutions first* as a priority wherever possible. As noted there seems to be a lack of priorities selection and comparative analysis in the existing knowledge base. We propose a simplified approach to this key question. Following the DOE example, initial questions will be as follows in a process of elimination when deciding on designing for enhanced air movement. This comes in addition to obvious steps such as reducing solar gain to a minimum through building orientation, roof overhangs, reflective roof surfaces etc.

1. General local climate: are significant local breezes available? If yes, then:
2. Specific site and building typology: will significant local breezes be available? If yes, then:
3. Specific building: will a relatively open plan and facades be functionally practical? If yes, then:
4. Specific users: can user friendly i.e. user operated solutions be applied? If yes, then:
5. What design features can be included (at x cost) to enhance air movement? ... etc.

In the case of very hot *and humid* climates, "no" answers along the above path will almost automatically point the designer towards *active* solutions. The next question may then well be, not "what is the most energy efficient active cooling technology?" but rather: "can this cooling need best be solved at the individual level or at macro scale?" This issue of individual versus urban scale energy solutions is largely overlooked in the research – just as it was until recent times in the cold climates of Europe. The field of district energy solutions is discussed by us in (x).

Grando School, Burkina Faso: earth blocks, passive cooling, source: Patti Stouter

7. CONCLUSIONS

In hot climates, energy use and climate emissions are increasing fast. Low income groups however have few amenities and poor conditions of health and comfort. There is a great potential for enhancing passive (and fan assisted) air movement design in low cost housing. This can include both new and existing housing. An important proviso is that in the case of low cost housing, this may entail *more, not less*, use of resources, the payoff therefore to be measured in terms of *avoided future impacts* (compared to BAU), not necessarily absolute reductions, in energy use or GHG emissions.

In contrast to much current research that focuses on specialised aspects and solutions, a key objective must be to achieve a comparative assessment ranking the effectiveness and practicality of the various possible strategies for passive design. The research should have a firm orientation to existing construction practices. It can provide important policy advice and sustainability guidelines, as a step towards building regulations for housing design.

Advances in knowledge and application of these passive strategies in low cost housing (both new and retrofit) would further the following goals:

-avoided climate impacts compared to increased future use of active solutions such as AC
-avoided future increases in energy use in the low income housing sector
-avoided costs for both equipment installation and energy purchases in the low income sector
-reduced urban heat island effect
-reduced dependence on unreliable energy supply systems in developing country situations
-promotion of new variants of culturally adapted vernacular traditions

Results will also have wide relevance for other building types. A key objective should be to link the research to existing initiatives, public bodies and other actors in housing provision, so as to achieve wide dissemination through publication, trainings and higher education.

8. PRELIMINARY REFERENCES

A very large body of research is available in journals such as *Energy and Buildings, Building and Environment, Building Research Information, Renewable Energy*, etc, as well as in a number of books. A full literature overview is not provided here nor fully standardised bibliography. Some items of note are as follows.

[1] ELITH: See www.elith.eng.cam.ac.uk 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.

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

[2] Givoni, Baruch. *Passive and Low Energy Cooling of Buildings*. Van Nostrand Reinhold, New York, 1994;

[2] Givoni, B. *Climate Considerations in Building and Urban Design*. Van Nostrand Reinhold, New York, 1998

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

[2] Szokolay, S. *Heating and cooling of buildings*, in: H.J. Cowan (Ed.), Handbook of Architectural Technology, Van Nostrand Reinhold, New York, 1991.

[2] Baker, N. et.al., 2001. *Climate Responsive Architecture: A Design Handbook for Energy Efficient Buildings*. Tata McGraw-Hill Publishing Company Limited, New Delhi.

[2] Ingersoll T G.et al., 1975. *Climatic Design in Manual of Tropical Housing and Buildings*. Orient Longman, New Delhi

[2] Santamouris, M., (ed.) *Advances in passive cooling*. Buildings, energy, solar technology. 2007: Earthscan.

[3] François Garde, Laetitia Adelard, H. Boyer, C. Rat, *Implementation and experimental survey of passive design specifications used in new low-cost housing under tropical climates*, Energy and Buildings 36 (2004) 353–366

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

[5] C.Y. Jim, S.W. Tsang, *Ecological energetics of tropical intensive green roof*, Energy and Buildings 43 (2011).

[6] S.V. Szokolay, *Heating and cooling of buildings*, in: H.J. Cowan (Ed.), Handbook of Architectural Technology, Van Nostrand Reinhold, New York, 1991, pp. 323–365

[7] Chris J. Koinakis, *The effect of the use of openings on interzonal air flows in buildings: an experimental and simulation approach*, Energy and Buildings 37 (2005) 813–823

(8) Berge, B. *The Engine isn't Responding. En kritikk av den automatiserte energisparebolígen*. Arkitektur N, Oslo 1-2011.

(9) Minna Sunikka-Blank & Ray Galvin (2012): *Introducing the prebound effect: the gap between performance and actual energy consumption*, Building Research & Information, 40:3, 260-273

(10) https://www.google.co.uk/search?q=cool+roofs+world+bank+india&ie=utf-8&oe=utf-8&client=firefox-b&gfe_rd=cr&ei=HvItV-vdFKizgAbd5aFQ#q=cool+roofs+world+bank+india&start=10

Others:

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.

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.

Bastide, A., et al., *Building energy efficiency and thermal comfort in tropical climates: Presentation of a numerical approach for predicting the percentage of well-ventilated living spaces in buildings using natural ventilation.* Energy and Buildings, 2006. 38(9): p. 1093-1103.

Tantasavasdi, C., J. Srebric, and Q. Chen, *Natural ventilation design for houses in Thailand.* Energy and Buildings, 2001. 33(8): p. 815-824.

Nguyen, A.T. and S. Reiter, *An investigation on thermal performance of a low cost apartment in hot humid climate of Danang.* Energy and Buildings, 2012. 47(0): p. 237-246.

Nguyen, A.-T., et al., *An investigation on climate responsive design strategies of vernacular housing in Vietnam.* Building and Environment, 2011. 46(10): p. 2088-2106.

Kubota, T., D.T.H. Chyee, and S. Ahmad, *The effects of night ventilation technique on indoor thermal environment for residential buildings in hot-humid climate of Malaysia.* Energy and Buildings, 2009. 41(8): p. 829-839

Chungloo, S. and B. Limmeechokchai, *Application of passive cooling systems in the hot and humid climate: The case study of solar chimney and wetted roof in Thailand.* Building and Environment, 2007. 42(9): p. 3341-3351.

Rajapaksha, I., H. Nagai, and M. Okumiya, *A ventilated courtyard as a passive cooling strategy in the warm humid tropics.* Renewable Energy, 2003. 28(11): p. 1755-1778.

Dili, A.S., M.A. Naseer, and T.Z. Varghese, *Passive environment control system of Kerala vernacular residential architecture for a comfortable indoor environment: A qualitative and quantitative analyses.* Energy and Buildings, 2010. 42(6): p. 917-927.

Leo Samuel, D.G.; Shiva Nagendra, S.M.; Maiya, M.P. (August 2013). *Passive alternatives to mechanical air conditioning of building: A review*. Building and Environment 66: 54–64. doi:10.1016/j.buildenv.2013.04.016.

Amer, E.H. (July 2006). *Passive options for solar cooling of buildings in arid areas*. *Energy* 31 (8-9): 1332–1344. doi:10.1016/j.energy.2005.06.002

Kwok A., Grondzik W. (2007). *The Green Studio Handbook: Environmental strategies for schematic design*. USA: Elsevier Inc. (Univ. of Indiana, thesis)

R. Kammerud, E. Ceballos, B. Curtis, W. Place, B. Anderson, *Ventilation cooling of residential buildings*, ASHRAE Transactions, (1984) 95(2), 226-251.

G.Z. Brown and Mark DeKay, *Sun, Wind, and Light*. Wiley.

Baruch Givoni, *Indoor temperature reduction by passive cooling systems*, Solar Energy 85 (2011) 1692–1726

J.Fergus Nichol, *Adaptive Comfort: Principles and Practice*. Amazon, 2012.