II

RESEARCH ARTICLES

DEVELOPING A HOLISTIC PATHWAY TO CLIMATE-ADAPTIVE BUILDINGS

Steffen Lehmann[1]

ABSTRACT

This paper explores the origins of an air-condition dependency which evolved with 20th century architecture and is related to other developments that affected buildings in the last century, such as the lack of flexibility/adaptability of buildings and their short life span. It then looks at some passive design principles as frequently found in heritage buildings from the pre-air-conditioning era, which are based on heat avoidance and harnessing of natural energies. The paper concludes with a series of recommendations for a holistic pathway to zero-carbon, climate-adaptive buildings.

KEY WORDS

tropical climate; indoor comfort; pre-air-conditioning era; mechanical systems; pathway to zero-carbon

AIR-CONDITION DEPENDENCY AND THE APPLICATION OF PASSIVE DESIGN PRINCIPLES

The built heritage plays an important role in the shift towards a low-carbon society; it also offers a large resource of knowledge about design principles and how architects used to operate within the challenges of a tropical climate. However, this role and knowledge base have not been sufficiently discussed and researched.

To conduct such research is particularly relevant for the future of the Asia-Pacific Region, where we can find rapid (and often traumatic) urbanization processes combined with too much reliance on outdated models of urban growth and building designs. This includes an unusually high dependency on mechanical (air-condition) systems, thereby creating large CO2 emissions and high operating costs in both residential and commercial building stock.

In current discussions about sustainability and climate change, we can see a re-appreciation of the built heritage. This built heritage has frequently been in harmony with the climatic condition of the geographical location, even in a challenging climate such as in the tropics, with its high degree of humidity.

The Asia-Pacific Region's humid tropical climate poses a particular difficulty, with temperatures often around 30 degrees Celsius during day-time, and around 24 degrees Celsius at night, and a high relative humidity of about 90 per cent. These conditions leave little scope for night-flush cooling. Serious climate engineering strategies are needed and the dehumidification of the air as part of a cooling process is a preferable option. There are some particularly exciting developments in the innovative area of 'solar cooling,' and around 300 installations worldwide now use solar cooling technology (data: 2009).

However, the excessive use of energy-intensive climate-control technologies, such as mechanical (electronic) air-conditioning and other 'quick techno-fix solutions,' have led to high expectations of indoor living standards and the complacency of architects to solve it 'by simply putting in the air-condition technology.' The ubiquitous use of air-conditioning systems across the Asia-Pacific Region consumes a vast amount of energy and has made 20th century building types, with deep plans, fully dependent on the technology. The question of how much the indoor climate should follow the outdoor climate requires new discussion.

The fully air-conditioned building also raises health questions. The other issue are high expectations by tenants of modern office buildings: Still, most building codes require that a maximum of 25 degrees Celcius indoor temperature is not exceeded at any time, even with 40 degrees Celcius outdoors;

[1]UNESCO Chair in Sustainable Urban Development for Asia and the Pacific Chair, The University of Newcastle, Australia. steffen.lehmann@newcastle.edu.au.

this is nearly impossible to achieve without mechanical ventilation. With global warming, it is probably time to update this part of the building codes.

In addition, the following questions are raised:

- How can energy saving be achieved without losing expected comfort level (e.g. legislation requiring max. 25 degrees Celsius indoor temperature at any time)?
- How to allow as much natural light as possible into office spaces while also reducing solar heat gain?
- How to sustainably cool buildings with large glazing areas in the tropics?

Furthermore, in the light of globalization, it is understood that the existing (authentic) built heritage is a significant contributor to local identity, and in building the unique character of any location, helping to achieve social outcomes and maintaining the memory of a place. The diversity of and the rich complexity of this tangible and intangible heritage is a constant inspiration that deserves to be maintained and protected.

FIGURE 1. A typical electrical air-condition system: Small fan-coil systems such as this can be installed during building use. Cooling requires 5 to 8 times the energy needed compared to heating. Instead of phasing them out, these energy-hungry air-condition systems where the fan-coil blows the cold air blows directly onto the occupants, are still enjoying a high popularity in Asia, Australia and the US. The ubiquitous use of air-conditioning consumes vast amounts of energy. Of all the major appliances in the home, air-conditioners and refrigerators consume the most energy in the monthly electricity bill. Half to two-thirds of the energy consumption of a typical household in Asia goes to operating air-conditioners and refrigerators.

ARCHITECTURE'S EVOLUTION IN THE 20TH CENTURY

While there were many wonderful innovations that transformed architecture and the building sector during the 20th century, there were also some less fortunate developments. The unfortunate path of development, which much of architectural design has taken in the 20th century, has been widely discussed in literature as a critique of functionalism and modernity. From 'Silent Spring' (by Rachel Carson, 1962), to Reyner Banham's 'Architecture of the Well-tempered Environment' (1969), to Ian McHarg's 'Design with Nature' (1969), to the pivotal publications by authors re-connecting urbanism with the climatic condition (such as Koenigsberger, or Drew and Fry, in publications in the 1960s and 70s), the field of sustainable city theories and climate-responsive architecture has constantly been expanded. Architect Otto Koenigsberger, for instance, immigrated from Berlin to India in 1939 and served there as a government architect until 1951, before he became one of the founders of the Department of Tropical Architecture at the Architectural Association School in London, fundamentally transforming architectural thinking and practice with his 'Handbook of Tropical Architecture': He recognized as early as 1950 the limits of resources and energy. Through his experiences in India, Koenigsberger theorized Tropical Architecture as a discourse that was climate responsive and energy conscious, and which used local resources, materials and workers in a sustainable way. Short supply chains of local construction material are always a first basic step towards achieving sustainability.

While we explore how renewable energy sources will be able to provide sufficient power for an ever increasing world population to maintain today's lifestyles, we could also ask, in which way our lifestyles should adapt to the needs of a future low-carbon society, through behavioural change in the use of energy, water, materials and the automobile. This question was frequently raised by architects Geoffrey Bawa and Glenn Murcutt, both very experienced in designing for the tropics. They called it: "to do more with less" (Bawa, Murcutt). Obviously there are different ways to look at the phenomenon of the artificially conditioned house, and we are well advised to not exclusively rely on quantitative measures only.

Values and aspirations associated with modernity and combined with new everyday expectations of comfort have evolved in tandem with lifestyle changes. Some of the mis-guided and often criticized developments of architecture in the 20th century include:

- Deep plan buildings.
  Correcting development: Slim buildings for light + cross-ventilation.
- Inflexible, specialized typologies.
  Correcting development: Universal, adaptable building types.
- Short life-span of buildings.
  Correcting development: Buildings that last longer(60+ years).
- Indoor-comfort depending on mechanical air-conditioning.
  Correcting development: Mixed-mode system, with operable window and night-flush cooling.
- The automobile-dependent city.
  Correcting development: Strong focus on walking, cycling, public transport.

Not only technological shifts are required to reduce carbon emissions, but also social, cultural and political ones. (Winter, Widodo, 2009) What are the obstacles for re-orienting lifestyles away from electronically chilled climates? It is time to move beyond technical scientific prescriptions of comfort and to consider how social norms have shifted, to examine the socio-cultural transformations brought about by the introduction of air-conditioning. What is the cultural perspective on air-conditioning today, evaluating also the qualitative criteria?

Heritage architecture of the pre-air-conditioning era, ranging from small residential dwellings to large civic structures, offers a resource and ‘living laboratory’ for more sustainable livelihoods. While the historical buildings form the pre-air-conditioning era frequently display a valid alternative (and there are revival trends visible)—here comfort can be achieved with natural cross-ventilation and effective sun-shading for most of the year—the internal loads have become problematic for all architectural design: the office equipment produces so much ‘hot air,’ and therefore requires some form of mechanical ventilation (e.g. as mixed-mode system, which is the combination of natural ventilation with some well-considered active system).

In the last decade or so, architects have frequently raised the issue of traditional ‘rule-of-thumb’ for passive design principles, which do not

FIGURE 2A, B. Carefully restored 2-storey ‘Chinese Shop House’ typology in Melaka, Malaysia (used by NUS as TTCL Centre for Architecture and Urban Heritage, 2009). A series of well-proportioned courtyards ensures good day-lighting and cross-ventilation within the 200 years old structure. (photos: Lehmann)

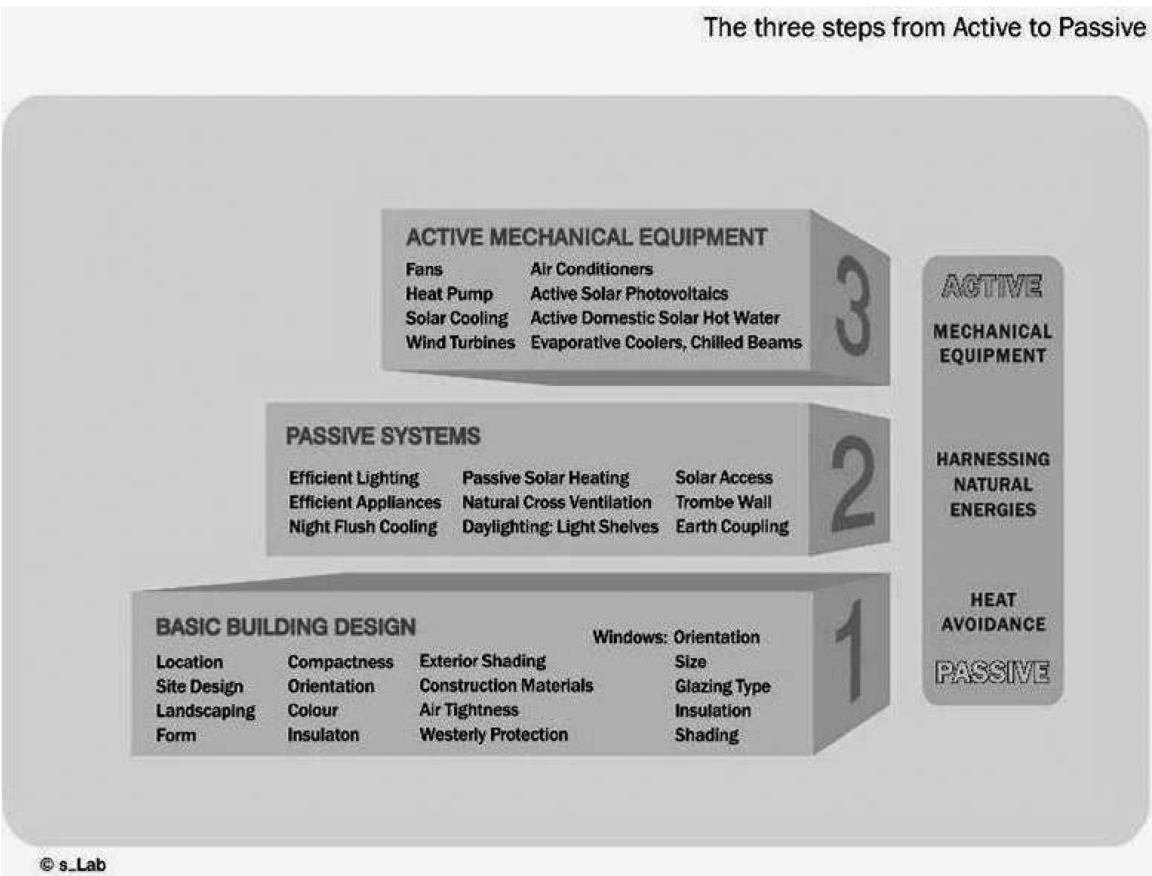
sufficiently quantify the effects. We can even find that the application of traditional rules of passive design do not apply to the new building types at all (particularly in the area of day-lighting, thermal mass, or air flow in double skin facades; while large glass surfaces of modern buildings facing the sun are almost always creating climatic problems due to the extreme heat gain), where it is increasingly recognized that a performance-based, quantifiable guidance for designers is needed.

BEHAVIOURAL ISSUES REGARDING THE USE OF WATER AND ENERGY

The twentieth century saw not only the introduction of mechanical air-conditioning systems, but also the specialization of building typologies. This generally led to reduced flexibility and adaptability to changing programmes of usage or demographics.

One issue to consider is the behavioural (mis)use of energy, water, materials and the automobile. To transform society towards a low-carbon future means tackling challenges that extend far beyond the question of sustainable design. The obstacles to re-orienting lifestyles away from electronically-chilled climates are wide, and the reintroduction of traditional passive design principles alone is unlikely to overcome these barriers. The solution is most likely to be a combination of passive design principles with some well considered active systems, for buildings that are built to last longer.

FIGURE 3. The three steps, from passive design principles to active. (diagram: Lehmann, 2006) Basic and passive design principles come first, with the aim to avoid heat gain in summer, before any mechanical systems are added.



Studies in energy consumption and ecological footprint have revealed that the most sustainable buildings are the ones that already exist (based on their primary embodied energy and material flow). (Lehmann, 2006)

Buildings from a pre-air-conditioning era frequently display a convincing application of passive design principles, such as optimizing orientation, the use of evaporative cooling, strategic use of thermal mass, trompe walls, ingenuitive sun-shading devices for the western façade, solar chimneys, allowance for cross-ventilation of hot air at the highest point in the room, and natural cross-ventilation adjustable to the changing directions of a breeze. Sub-slab labyrinths, activating the thermal mass, have seen a recent comeback in many new projects. We can also find that the use of local materials (combined with local work force and locally available technical know-how) has frequently created a regional or vernacular local 'style' in architecture.

However, today it's seen as necessary to not just engage in a revival of these passive (and basic) design principles, but to update these traditional 'rules of thumb' and place them within a robust scientific framework, for a better evidence-based understanding and adjusted to the reality of contemporary construction methods. There is now a need to redefine and update the applicability of the passive design 'rule of thumb' strategies.

RECOMMENDATIONS AND DISCUSSION

The transformation of the built environment requires exploration in all three areas: research, teaching and practice.

Part of the mission of the UNESCO Chair in Sustainable Urban Development for Asia and the Pacific is to conduct relevant interdisciplinary research and capacity building, and to strengthen the professional capacity, to appropriately appreciate and deal with authentic heritage. The mission includes establishing a research network with a particular focus on the urban built environments of the Asia-Pacific Region, with the aim of disseminating relevant knowledge throughout the region.

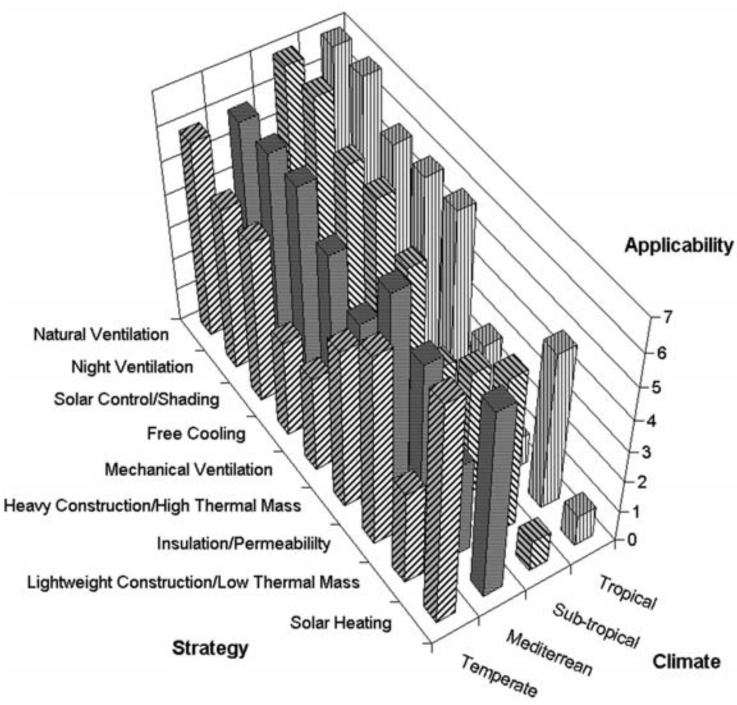
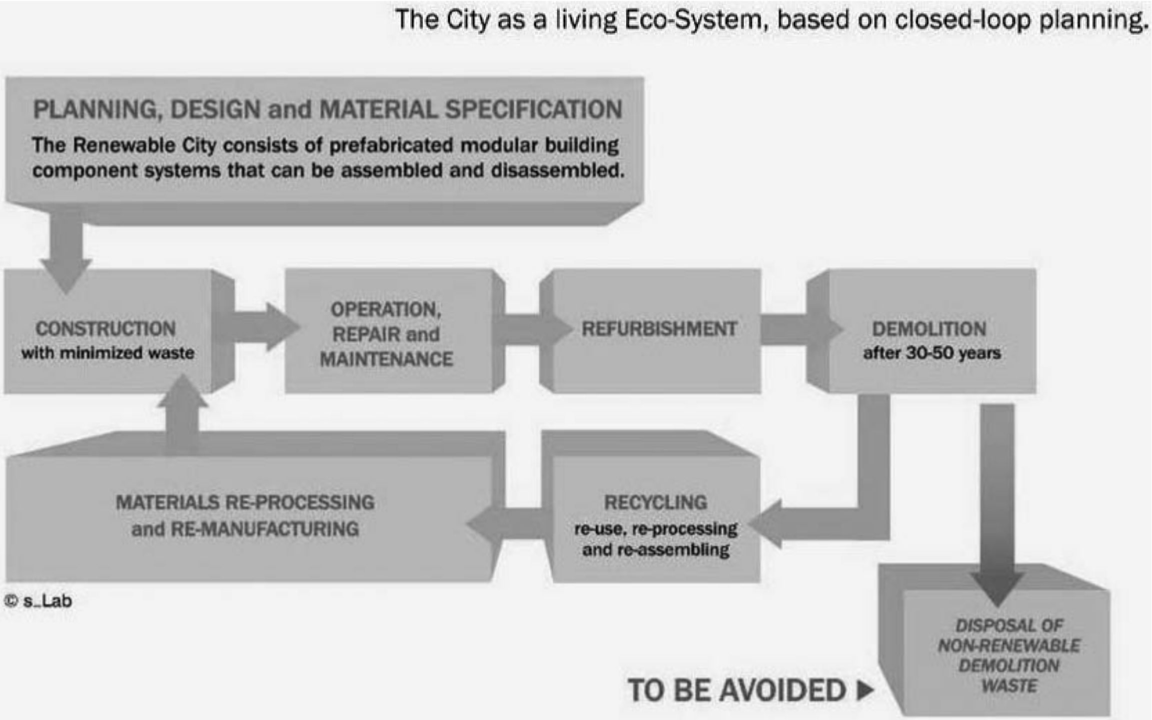


FIGURE 4. Applying the right strategies depending on the climate. Some strategies that might work well in a Mediterranean warm and dry climate will not be applicable in the tropics. (diagram: Shiel, 2008; UNESCO Chair)

FIGURE 5. Buildings and cities as living eco-systems; existing buildings and built heritage plays a particular role in this cycle. (diagram: Lehmann, 2006)



Following are five recommendations for sustainable urban development and the integration of built heritage in masterplanning for urban growth.

Develop compact urban form at transport nodes: A resilient network

Land use, planning, and design controls, together with building codes, require more consistency at all levels of government to ensure housing location and types deliver a compact urban form with higher densities around transport networks. This will require an integrated framework cascading from national to district government levels, with rigorous implementation.

However, there is a danger of overly increasing density and in changing land-cover through development. This can reduce natural urban ventilation and increase the risk of Urban Heat Island. A better balance is necessary! (E.g. Hong Kong has developed the Air-Ventilation Assessment System in 2008, with the aim of creating better air flow and breezeway corridors). It is necessary to favour inner urban diversity and density, including the reinvigoration of existing inner urban shops, schools and community facilities, and also to develop along boulevards and transport corridors to support public transport and promote walkable cities.

Evolve towards 'Eco-infrastructure,' implemented in unison with climate responsive built form

Currently, legislation discourages integrated precinct resource management. Regulations need to be changed to allow distributed renewable energy networks and non traditional water supply systems to be implemented. It is important to develop nationally recognized equitable contracts for ESCO, energy and water supply services that cover all stakeholders, to avoid transactional cost issues. Precinct prototyping of smart grid systems is an immediate need due to lead time and must be incentivized.

Methods for assessing climate change resilience must be implemented by district regulations. Current policy tools, such as the LEED, GreenStar, or BREEAM assessment tools, must be used to affect landscape design, site resilience and resource management.

De-carbonizing the energy supply on the district-scale is necessary. Low-emission energy generation technologies can turn the city districts themselves into power stations, where energy is generated close to the point of consumption. Localized energy generation using renewable energy sources (solar, wind, biomass, geothermal), complemented by distributed heating and cooling systems, has a huge potential to reduce the built environment's energy demands and emissions. Such decentralized, distributed systems, where every citizen can generate the energy needed, will eliminate transmission losses and transmission costs (which always occur with large grids and inefficient base-load power stations) for the local consumer.

The concept works for both existing and new buildings. Small power generators are positioned within communities to provide electricity for local consumption, and the waste heat they produce is captured for co-generation (for CHP; or for tri-generation, when waste heat also produces chilled water for cooling), and used for space conditioning via a local district heating or district cooling system. New exergy principles look to capture and harvest waste heat and waste water streams, and also at how the strategic arrangement of a programme within mixed-use urban blocks can lead to unleashing the unused energy potential. Urban greenery needs to be integrated to reduce and mitigate the Urban Heat Island effect.

Develop a policy pathway to zero-carbon: More ambitious targets

A trajectory towards a de-carbonized Asia-Pacific Region needs to be established. This should involve long-term overall targets, as well as medium to short-term targets, subdivided into sectoral responsibilities. Evolving policy and regulatory frameworks need to reflect the trajectory.

Given the relative long life of buildings, targets (both for refurbishment and new-build) need to reflect longer term contributions to the trajectory (buildings that last longer).

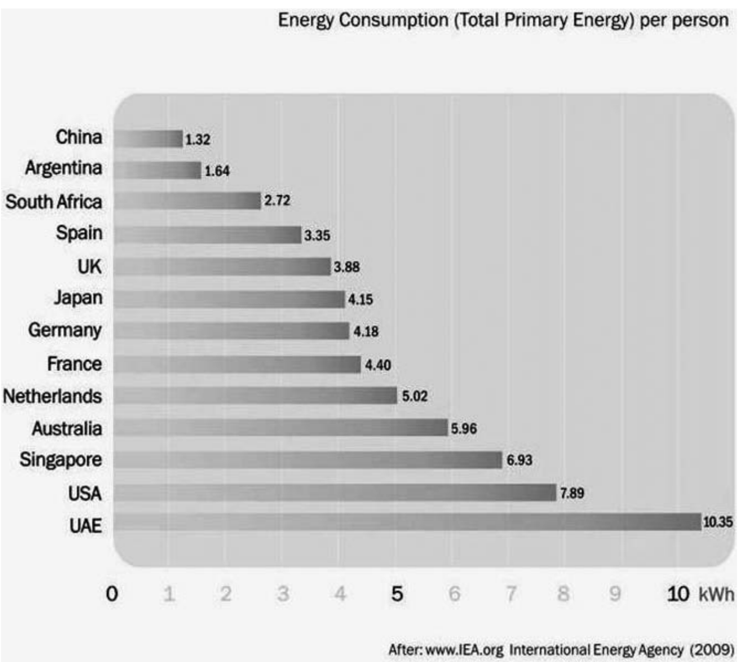


FIGURE 6. Energy consumption, Singapore in comparison with other states. China's energy consumption is fast increasing, due to the installation of air-condition units. (diagram: Lehmann, 2009)

Assessment ratings should be initiated for energy standards, with the highest rating given to zero-carbon emissions.

Develop a holistic pathway to climate-adaptive buildings

A clear vision of what constitutes a climate adaptable and resilient building needs to be established complete with appropriate overall regional variations. These adaptive measures need to be embedded within assessment tools, and progressively introduced as experience of the building regulatory framework grows.

Examples of such measures (suitably quantified) might include:

- Extended-life buildings with the ability to accept change of usage (long life-loose fit). Among other aspects this impacts on depth and massing of buildings.

FIGURE 7A AND B. A good example of the use of passive design principles: The Raffles Hotel in Singapore, built around 1894-99, with its airy verandah and Palm Court. In 1899, the hotel boasted Singapore's first electric fans. (Photos: Lehmann)

FIGURE 8A AND B. Cooling chimneys using evaporative cooling and the stacking effect of hot air: the Wind Towers of Yazd. Called 'Baadgeer', these wind catchers are characteristic of the central Iranian city of Yazd. As the name indicates the wind catchers were (and are) built to keep the buildings cooler during the hot and dry summers when the heat gets unbearable. The wind catchers are designed to catch even the smallest movement of air and direct it downwards to cool the living quarters below.

- Using thermal mass (heat storing) materials into building structures.
- The ability to operate buildings completely passively (without energy consuming systems operating) for large proportions of the year.
- Installing district cooling systems that utilize the waste heat through tri-generation systems.
- Reducing the volume of materials needed by buildings, particularly the frequently replaced components. Urban Heat Island reduction measures to allow reduced capacity energy consuming building systems (electric vehicles, transport modal switching, extensive urban vegetation to mitigate UHI, and associated urban rainwater retention)

Built environment education, training and research must take climate change mitigation and adaptation as a main intent

The building industry is currently not trained to renovate existing buildings to the new low carbon and climate adaptable standards, and nor is it set up to deliver them. Professional education does not sufficiently prioritize or effectively deliver curricula that empower graduates to shape a zero-carbon and climate adaptable urban environment. Therefore,

FIGURE 9A, B, C. Architecture in tropical Australia, by Glenn Murcutt, Troppo, and others, revitalizing the idea of a shaded 'verandah', where the house has a summer part and a winter part, adapting to seasonal changes. Image c: Bowali Visitor Centre, Kakadu Northern Territory (Australia), 1992, by Glenn Murcutt and Troppo Architects. Aboriginal people have always lived an outdoor life. (photos: Courtesy G. Murcutt)

reform and expansion of built environment education and training, with climate change mitigation and adaptation as its main intent, must occur within the next five to ten years.

Mass industry re-training over the next ten years to provide the necessary leadership and capacity to engage in the mass renovation of existing buildings is a necessity, as is intensified interdisciplinary research activities that deliver a framework for the transition to a zero-carbon building sector. Much of our housing and workplace models (existing stock and current production) are inadequate and repeat out-dated ideas, thus they cannot deal with the immense challenges ahead. Clearly there is a need for more research, with a focus on future-proofing urban design, on architecture and the entire building sector, and which celebrates diversity.

Therefore, research needs to identify best practice and its applications in a holistic way, developing performance-based principles for compact urban form, energy-effective buildings, and more flexible, adaptable building typologies, in order to re-conceptualize a new generation of housing and workplaces. Better methodologies for measuring sustainability, resource management and material flows need to be researched and developed.

CONCLUDING REMARKS: REDUCING THE URBAN HEAT ISLAND EFFECT AND MINIMIZING THE NEED FOR AIR-CONDITIONING

In the tropics, climate-appropriate urban design strategies (Aynsley, 2006; Rudolph, 2008; Lehmann, 2007; Shiel, 2009) include:

- orientating narrow streets with buildings of appropriate heights to reduce heat build-up during the day and to shade pedestrians, e.g. have narrow streets running North-South,

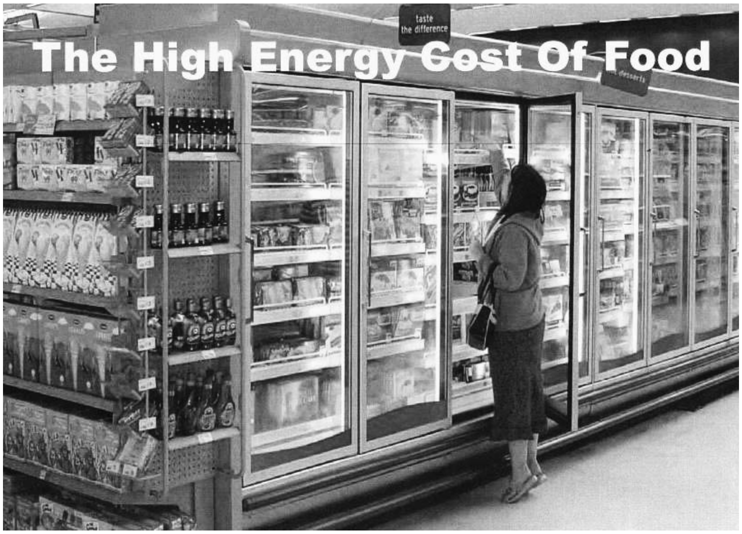


FIGURE 10. In average, food travels 3000km from field to plate. The embodied energy of food has emerged as a critical topic.

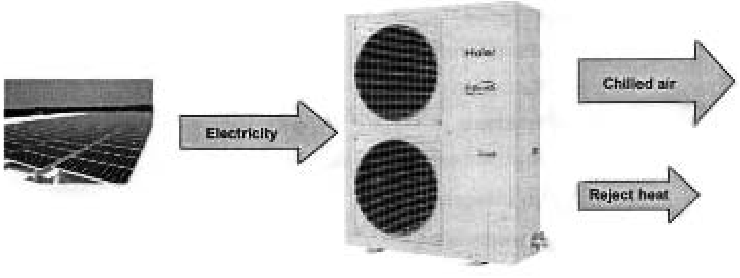


FIGURE 11. New solar cooling technology produces chilled water through solar radiation. There are now around 300 systems installed worldwide (data 2009).

- to manage street breezeways without creating 'wind tunnel effects,' and
- to ventilate and have convective (night-flush) cooling at night.

Strategies to reduce the Urban Heat Island (UHI) effect (see Figure 12) in the tropics are important to reduce GHG emissions (Ichinose et al., 2008). According to Shiel, these fall into three main groups: reducing the heat from energy consumption; using less heat-absorbing materials on the ground and on urban structures; and ensuring airflow through cities (Yeang, 2006; Ichinose et al., 2008; Shiel, 2009). These strategies are shown in Figure 12, and they consider the most effective ones to be:

- Reducing air-conditioning cooling loads, e.g. with external building vegetation,
- Using water-retentive paving,
- Using the albedo effect of light coloured walls and roofs to lower room temperatures,
- Increasing green tracts of land;
- Creating water channels and bodies of water, and
- Relocating green land or business facilities to take account of sea breezes and other prevailing winds.

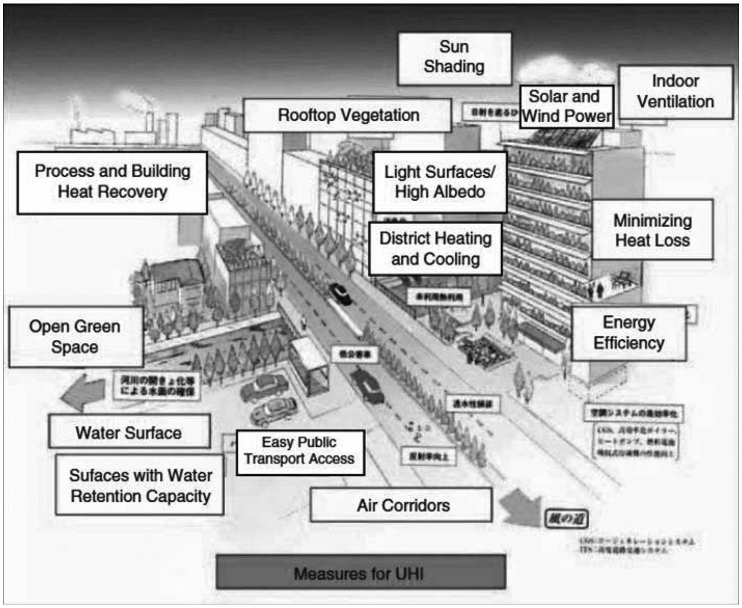


FIGURE 12. Reducing the Urban Heat Island effect (source: Ichinose, 2008; Shiel, 2009).

FIGURE 13. Solar-Stadt, Freiburg, Germany (architect: R. Disch). The city district as power-station, generating energy locally with small, decentralized systems and supplying district heating/ cooling. The available solar power is immense: The earth receives at any time, every hour, more energy from the sun than the entire world's population uses in a whole year. These so-called 'Energy-Plus' houses are highly insulated buildings, where the full roof is covered with PV cells, and additionally generated electricity is fed into the grid.

Other measures include refurbishing buildings for energy performance to lower air- conditioning demand; using district cooling techniques e.g. CHP, geothermal, or water from rivers or harbours.

REFERENCES

Aynsley, R., 2006. *Guidelines for Sustainable Housing in the Humid Tropics—Parts 1, 2 and 3. Heritage and Strategies for Design*.

Head, P., 2008. *Entering an Ecological Age*, Arup. Available at: http://www.arup.com/.

Ichinose, T., Matsumoto, F. & Kataoka, K., 2008. *Counteracting Urban Heat Islands in Japan*. In: Urban Energy Transition (Droege, P., 2008), Elsevier, Amsterdam.

IPCC, 2007. *Technical Summary*. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the IPCC [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer (eds)], Cambridge University Press, Cambridge, UK.

Koenigsberger, Otto. *Manual of tropical housing and building: Climatic design*. Longman, London, 1980.

Lehmann, S., 2007. *Sustainability on the Urban Scale: Green Urbanism*. In Urban Energy Transition (Droege, P., 2008), Elsevier, Amsterdam.

MacKay, D., 2008. *Sustainable Energy—Without the Hot Air*, Cambridge, UK.

McHarg, I., 1969. *Design with Nature*, London.

Shiel, J., 2008. *Strategies for practical greenhouse gas reductions in the existing building stock*. In:The Proceedings of ANZAScA 2008. University of Newcastle, Australia.

Stern, N., 2006. *Stern Review: The Economics of Climate Change*, Chancellor of the Exchequer; UK.

Winter, T. and Widodo, J., 2009. SOCooLH: Sustaining Our Cool Viving Heritage, workshop in Melaka, Malaysia, organized by NUS, ARI and University of Sydney.

Yeang, K., 2006. *Green Design in the Hot Humid Tropical Climate. In Tropical Sustainable Architecture—Social and Environmental Dimensions*. Burlington, MA, USA: Elsevier.