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Abstract	For the first time in history, since 2007 over half the world's populations live in cities (Laski and Schellekens, Growing up urban. In: Marshaland A, Singer A. (eds) The state of world population 2007 youth supplement. United Nations Population Fund (UNFPA), New York, 2007); clustered together in communities, neighbourhoods, districts and cities that may consume as much as 75 % of global energy (Asif et al., Build Environ 42, 2007; Lehmann, Low carbon cities: transforming urban systems. Routledge, London/New York, 2015), although occupying only 3 % of the global land surface (UNEP, Global initiative for resource efficient cities. UNEP, Paris, 2012). Buildings alone account for 40–50 % of the world's energy consumption. Developing countries have lower climate emissions per capita due to generally lower energy use, but they are set to overtake developed nations, as urban population increase will predominantly be in developing countries (Jiang and Tovey, Energy Policy 37(11): 4949–4958, 2009). This book addresses cities, where the main energy need for indoor comfort is cooling. There are other contexts where much of our discussion is relevant. In many climates, there is some need for winter heating even if the requirement for most of the year is for cooling. Many inland continental cities, for example in central Europe and the US Midwest, have both extreme heating and extreme cooling seasons. Yet sustainable city planning and building applies similar principles in all climates, if with opposite solutions—for example keeping heat out as opposed to keeping it in, or maximising cooling breezes as opposed to avoiding the chilly effect of cold winds. There will always be local or regional particularities: local weather constraints, such as, smog, rain or inversions; local opportunities, such as, prevailing breezes, water bodies, and local renewable sources of energy.	

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CHAPTER 2

Cities, Climate and Cooling

Chris Butters and Ali Cheshmehzangi

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CITIES AND CLIMATE

For the first time in history, since 2007 over half the world's populations live in cities (Laski and Schellekens 2007); clustered together in communities, neighbourhoods, districts and cities that may consume as much as 75 % of global energy (Asif et al. 2007; Lehmann 2015), although occupying only 3 % of the global land surface (UNEP 2012). Buildings alone account for 40–50 % of the world's energy consumption. Developing countries have lower climate emissions per capita due to generally lower energy use, but they are set to overtake developed nations, as urban population increase will predominantly be in developing countries (Jiang and Tovey 2009). This book addresses cities, where the main energy need for indoor comfort is cooling. There are other contexts where much of our discussion is relevant. In many climates, there is some need for winter heating even if the requirement for most of the year is for cooling. Many inland continental cities, for example in central Europe and the US Midwest, have both extreme heating and extreme cooling seasons. Yet sustainable city planning and building

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applies similar principles in all climates, if with opposite solutions—for example keeping heat out as opposed to keeping it in, or maximising cooling breezes as opposed to avoiding the chilly effect of cold winds. There will always be local or regional particularities: local weather constraints, such as, smog, rain or inversions; local opportunities, such as, prevailing breezes, water bodies and local renewable sources of energy.

There is a fundamental difference between hot-dry and hot-humid climatic conditions. Most Asian cities have hot-humid climates, whereas the Middle East and many African regions have a dry climate. In general, the hot-dry context is easier to address. In hot-dry climates, where there are often cooler nights, massive buildings help to maintain lower temperatures and this can be aided by evaporative cooling and other traditional measures; there are few such options in hot-humid climates. But in both hot-dry and hot-humid climates the two key principles for keeping cool are the same: solar protection and maximising air movement. These two apply both to the design of individual buildings and to the layout and design of streets and outdoor spaces. Whilst using these natural or ‘passive’ strategies can considerably reduce city temperatures, in the tropics they are often not sufficient alone and added ‘active’ cooling technologies are needed.

The main sources of energy use, and hence, of both heat and greenhouse gas emissions in cities are buildings and vehicles. We touch on transports only insofar as urban layout influences transport requirements. Energy for buildings—and for urban infrastructures—includes both the energy needed to operate them with cooling, lighting and so on and, importantly, the energy used to produce them. This embodied energy forms a very significant part of the overall picture; increasingly so as operational energy becomes ever more efficient. We return to this below. Space cooling in hot climates represents *the* largest energy need in buildings, often over half the total.

Energy needs are influenced by many physical factors including city density, layout, green space, building design and technology. Three main approaches to reducing them are: improved *design*, such as, passive cooling and low embodied energy materials; improving *technological efficiency*, such as, for lighting or air conditioners; and addressing energy *behaviour*. All three can be partly solved at urban rather than individual scale. Urban layout and building design can improve local microclimates, reducing ambient temperatures and hence cooling needs. District energy systems for cooling are technically much more efficient than individual ones. Planning and

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transport solutions as well as city management can promote energy saving and reduce travel, again reducing unwanted city heat.

Cooling in hot climates was traditionally achieved by vernacular solutions, which often demonstrate extremely intelligent ‘design with nature’, both for buildings and for town location and layout. Today, the universal trend is to mechanical air conditioning (AC); mostly with individual AC units in each building. Each unit ejects waste heat into the environment, thus just heating up its neighbours and increasing the energy load and urban heat island effect even more. Apart from its cost, AC can have drawbacks including noise, health risks, and the fact that it requires high quality (exergy) electrical energy. Improving the efficiency of AC is, thus, only a part solution, and helps little if, as in many cases, the *volume* of AC is increasing so rapidly that it outstrips the efficiency gains.

Good urban planning and building design provide free, passive cooling and reduce or even eliminate the need for added mechanical cooling. Passive solutions, discussed more in our examples, are the top priority. There are many reasons for this: first, to minimise the energy needed; second, they tend to be cheaper than energy supply; third, because passive solutions are robust since they are ‘the building itself’; whereas all technology, renewable or not, is susceptible to lower than expected performance, incorrect use, and breakdowns. An energy efficient window is usually more cost-effective and lasts longer than a solar panel; the shading and cooling effect of trees is cheaper and longer lasting than cooling supplied by an AC unit.

Whereas technical efficiency is important, it does not solve the key issue of the urban heat island (UHI). Essentially, what is needed is to remove the sources of heat from the city environment. The key is to address cooling not at individual building level but at an urban scale instead. District energy systems, which are not yet widespread, are discussed in Chap. 11; district cooling is *almost the only* solution to UHI in hot-climate cities.

The role of green spaces and vegetation in moderating the urban microclimate is important too. They have been shown to considerably lower city temperatures, in addition to other environmental benefits, such as filtering air pollution and reducing noise. This field has been widely studied; several of our chapters provide examples of research in the Asian context. Location, layout and design of a city’s green infrastructures can reduce temperatures, as well as providing outdoor wellbeing, biodiversity, leisure and social spaces.

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WHAT KIND OF CITY?

A worldwide tradition of living in low-rise housing is giving way to life in urban apartments. This brings huge socio-cultural changes. Our paradigms of urban form include European city typologies, modernist zoning, dense high-rise, garden cities and suburban sprawl; with widely differing *economic* and *social*, as well as, *ecological* characteristics. Whilst many argue for 'human scale', others praise the dynamic qualities of megacities, although few would deny that their scale and complexity imply strenuous administration and governance, including for infrastructures, transport, energy and other services. The popular 'compact city' paradigm offers advantages especially in terms of urban transport efficiency, but also a 'compact' concentration of negatives: high land prices, congestion, air pollution and noise.

Principles for sustainable building and cities are well known, but are seldom applied in a rush for development; coupled with a rather uncritical trend towards high-rise, or outdated zoning models from the modernist era. In addition comes the free rein given to private cars, with their impacts on the environmental as well as social characteristics of cities. High-rise developments are a common model, especially in the emerging economies; not only for business districts but also for residential areas. By contrast, European cities, such as London or Berlin, have pockets of high-rise but consist largely of low-rise, medium density urban fabric. At the other extreme lies the very low density 'sprawl', widespread not only in North America. It is notable, however, that high population densities can be achieved in quite low-rise cities, such as those in Europe (LSE/Eifer 2014). We have discussed elsewhere how dense high-rise entails far higher embodied energy, debatable economies of scale and few energy efficiency advantages, in addition to the many positive social qualities of low-dense type towns (Cheshmehzangi and Butters 2016). Many people believe that high-rise is a necessity in order to house growing populations, but this is not the case.

Rapid growth combined with a lack of resources often leads to poor solutions. The fast pace of development in countries, such as China, can be illustrated by the following: 'almost 80 % of the residential construction projects in Xiamen Island were built after 1990, whereas only 6.7 % of the construction was built before 1980' (Ye et al. 2011). Such rapid growth is problematic, often being at the expense of local environments and of living quality. It often implies hasty urban development. The same rapid growth applies to energy use: in Thailand, household energy use is projected to

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double by 2030, and over 70 % of this is in the urban sector (Chirarattananon et al. 2014); in Chinese cities like Ningbo, air conditioning (AC) in households has been increasing by 10 % per year (Ningbo Annual Statistics Yearbook 2013).

Most of the above points have particular relevance for low-income contexts, which are prevalent in many developing country cities. Whilst energy and climate emission aspects are our focus, here again we must 'join the dots' and think holistically: for example, about *economic* and *social* arguments for low-rise, including, classic qualities relating to identity, security, human scale and conviviality. Dense high-rise urban environments require infrastructures and buildings of *a high standard* in order to be liveable and avoid environmental problems such as pollution, noise and UHI. In low-income contexts, which includes much of the planet, construction quality is frequently poor, which also argues against dense high-rise typologies as an appropriate model. For, whereas *high quality* compact cities may provide satisfactory conditions, *low cost* high-rise can often lead to little better than 'vertical slums'.

Over half of the world's population now lives in cities, in overall densities above 4000 persons per square kilometre; half of these live in cities of over one million inhabitants; and more than half of the largest urban areas are in Asia (Demographia 2016). We do not discuss the overall size of cities here, but regardless of size, the shaping of all cities has a large influence on energy use and climate emissions. In addition, as compared to individual buildings, which can more easily be modified or replaced, the overall city layouts and infrastructures have a very long lifetime, rendering future energy or emission improvements far more difficult. Hence, the added importance of long-term planning. City ideals have long been debated; but today's focus on energy and climate adds urgent new dimensions to planning choices. It is certainly useful to revisit known city concepts, some of which are advantageous when seen in the new light of sustainability. What layouts and spatial patterns can provide the coolest environments? The widespread paradigm of high-rise, compact cities needs to be questioned. We return to this question in the concluding section of the book.

COOLING

Heating, ventilation and air conditioning (HVAC) systems typically consume 30–50 % of the energy in domestic and commercial buildings (Gruber et al. 2008). In areas of high temperature and humidity, ventilation is one of

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the primary cooling tools for improving thermal comfort (Givoni 2011; Dawodu and Cheshmehzangi 2017). High energy consumption, shortages of conventional sources of energy and escalating energy prices have prompted a revaluation of conventional air-conditioning, HVAC, and design practices. There is renewed focus on passive energy design techniques to reduce energy consumption and improve thermal comfort and health whilst reducing environmental impacts (Geetha and Velraj 2012; Dili et al. 2011; Dawodu and Cheshmehzangi 2017). This view of passive design stretches beyond buildings and pertains to the entire urban environment from a neighbourhood scale (meso level) to city scale (macro level). AU2

Factors of human wellbeing including physiological comfort are partly subjective. It is well recognised that comfort is both individual and culturally variable (Nicol 2004; Kwong et al. 2014). In the tropical regions, temperatures of around 29–30 °C are widely perceived as quite comfortable. Scientific studies build on this knowledge using tools, such as the predicted mean vote (PMV) methodology. It is also recognised that occupants feel more comfortable in spaces where they can control their indoor temperature, as opposed to automated AC environments. This can also lead to lower energy consumption. But excessive temperature and humidity cause both discomfort and ill health, especially when combined with city air pollution, and in extreme cases mortality, which is foreseen to rise in future given both rising UHI effects and global warming. Access to natural environments and green space is also recognised as important for health (Hahtela and Wolgate 2013, Hanski et al. 2012). In addition, comes reduced productivity, a major issue for workplaces including offices and not least in the many thousand factories in the Asian economies. AU3 AU4

Both space heating and cooling involve small temperature differentials: we need to raise or lower the ambient temperatures by typically only 10–30 °C. It is, however, easier to tolerate high temperatures than it is to tolerate cold for any length of time. For thermodynamic reasons, heating is often easier technically than cooling. Available sources of free or nearly free heat in the environment are relatively plentiful; they include solar energy, waste heat from industries and geothermal (underground) heat. In cold climates, the free heat generated by lights, cooking, appliances and human bodies is also a useful source—whereas such indoor heat gains are unwelcome in hot climates. Available natural sources of cold, on the other hand, are far more limited; they can include cooler air available at night, and cool water from rivers, seas or lakes.

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The physical difference between heat, work and power—thermodynamic energy quality—is central in energy planning. Power, that is electricity or motive force, is high-quality (high exergy) energy and can be simply described as highly concentrated energy; hence, more difficult to achieve. The high-quality energy available from fossil fuels in our times has enormous value. By comparison, the energy of human labour, a large component of both costs and time in developing country construction, is almost negligible when compared to most energy inputs. For example, one kilo of plastic water pipe contains around 90 MJ of energy, which corresponds to roughly 200 hours of human labour. The energy needed to construct a small timber house is around 100,000 kWh (Venkatarama Reddy and Jagadish 2003). This corresponds to around 500 years of human 'work'—a telling reminder of how incredibly useful energy is to us.

The city as a built environment is itself a cause of the heat island effect, due to its form and the hard surfaces that trap solar radiation. This is where vegetation, lakes, green roofs, reflective surfaces and other passive measures all provide cooling effects. Cities also greatly hinder the other key means of natural cooling, wind, due to the dense layout and barriers to air movement formed by the buildings. Ways to address this are discussed in several sections of the book. However, the core problem with today's predominant energy solution, mechanical AC, is that in cooling individual spaces it rejects waste heat into the city air; thus increasing the overall heat in the city. Hence, there are three generic options. The first is that of climate-adapted 'design with nature', both on the level of individual buildings and that of urban layouts; in the best case this can eliminate the need for cooling for all or most of the year. The second is technological efficiency, reducing the amount of energy needed by appliances such as AC to deliver a given comfort level. The third option is to remove unwanted heat production from the inner city altogether. This solution, district cooling, presented in Chap. 11, is at the macro level, the only way to not only stop increases in city heat but to reduce it. It can be added that the same applies to the other major source of city heat, namely vehicles; to reduce this, one must remove the source of the heat from the inner city, either by reducing the volume of traffic or by replacing it as far as possible with electric and other non-heat producing transport modes.

Both passive design and natural ventilation are fast developing fields today; as is that of district cooling. In short, solutions exist but they are not widespread. The urgency of this is well recognised in Asia including

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within major organisations such as ASEAN; again, the main challenges are not technical but ones of resources, policy and implementation.

ENERGY AND CARBON

For readers less familiar with this field, we include brief notes here on energy versus carbon and operational versus embodied energy (OE, EE). In this book we refer generally to energy; the *carbon* (or climate) impacts of built environment correspond broadly to those of *energy* since energy supply systems are largely fossil-fuel based. A reduction of the *carbon* impact with significant *decoupling* occurs only when our energy supplies become largely renewable.

Energy is both a cornerstone of our lives and important due to its costs and impacts. Energy reductions generate cost savings, for people, and greenhouse gas savings, of global benefit. Energy is used in creating buildings and cities and again in operating them. The *carbon* angle is important due to climate change; carbon saved now is more 'valuable' than carbon saved in 100 years' time, by which point one assumes the climate issue will have been solved (or else it is too late anyway!). Energy is a permanent challenge, but even more today due to its correlation with the climate question. The energy footprint of buildings and other products should diminish over time as production processes become more efficient and as our energy is more and more from renewable sources. In the context of buildings and city infrastructures a major exception to this is the case of Portland cements, where the *chemical process* of production (calcination) emits more CO_2 than the production energy, and is a large factor in the lifetime footprint of many constructions. This one material is the source of roughly 5 % of global carbon emissions (Worrell et al. 2001). For sustainable building, we must in addition, consider toxicity to humans or the environment; this includes, substances that may not be important in terms of energy or climate (including SO_2, NOx, VOCs, formaldehyde, synthetic mineral fibres, lead, asbestos and the like).

Until recently, in colder climates, such as Europe, the energy used to heat buildings was by far the largest item. With recent low energy buildings, heat loss has been reduced to a fraction; electrical appliances, including, lighting are also now far less energy consuming. Since the *operational* energy is thus greatly reduced, the *embodied* energy to produce the materials becomes a far larger part of the total. This picture has only emerged over the last 15–20 years. The part played by the *materials* assumes great importance.

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The fields of OE and EE are well established but complex. Methodologies, assumptions and contexts require careful handling. The prevalent approach is life cycle analysis (LCA), which also has variants; adopted boundaries may be cradle-to-gate, cradle-to-grave or cradle-to-cradle—as well as limitations; for example the post-use phase does not account satisfactorily for residual energy/carbon (Sassi 2008). The focus of such studies also depends on the purpose; the perspective (and goals) of a manufacturer is different from that of a product designer, and different again from that of a climate scientist.

For buildings, and to a large extent for other products too, OE is most commonly accounted in terms of MJ or kWh, measured per area of building, to which one may add per year of lifetime or per whole lifetime. It is notable that building lifetime is often assumed to be 50 years, both in legal standards and for cost-benefit calculations. This, in our opinion, is too short to be called 'sustainable'. The lifetime assumption obviously has a big impact on the result. EE is similarly accounted in terms of MJ per kg of building material, eventually aggregated as MJ per unit area of building. For carbon, corresponding units are normally kg CO_2e per unit area or per kg of product. All other greenhouse gases (GHG) being converted to CO_2 equivalents; for example, 1 kg of methane has the same greenhouse effect as about 21 kg of CO_2. One thus arrives at an overall figure for a building's performance, which can be compared to other buildings, used to set up benchmarks or, in the design stage, to evaluate initial concepts and develop more favourable options.

Embodied energy and carbon figures vary widely. For example, aluminium made using renewable hydropower in Norway requires the same production *energy* per kg but has a much lower embodied *carbon* impact than aluminium that is produced in China using fossil fuels. If we use a database containing figures based on 'EU average' for aluminium production, we cannot directly compare to a building where the aluminium is produced using energy from oil or coal. Similarly, in developing countries, factory efficiencies may be much lower than those in, say, Europe. Hence, one must often revert to a detailed consideration of the *primary energy* picture.

Operational energy is the energy needed to run buildings. OE includes space climatisation, cooking, hot water, lighting and other appliances. In low-income contexts, it is very important because it requires a cash flow. In some developing countries cooking forms the largest home energy demand. In the rapidly urbanising low- to middle-income sectors, space cooling forms the main growth in energy use. As noted it can to a large extent be

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ensured by good building design using passive means, less easily in hot-humid climates, and not in polluted cities where outdoor air is undesirable. Being free, passive solutions are a priority.

Embodied Energy (or carbon) has received less focus. In low-energy buildings, the EE may constitute over half the *total* lifetime energy. A building's life has three main phases: construction, recurrent maintenance or modification, and final demolition. EE is the total energy used over the building lifetime for manufacturing its components, transport, assembly on site, lifetime maintenance and final post-use disposal. Production of the materials normally accounts for the bulk of the EE. Vernacular building uses natural materials like earth, stone, timber and other vegetal products. These have environmental advantages, such as low energy intensity, local availability and biodegradability. With energy and climate in focus, the traditional materials are regaining interest.

Means of reducing EE include selecting less energy-intensive materials, using less material, increasing the efficiency of material manufacture and extending building life. In hot-dry climates, heavy materials are often favourable, but lightweight solutions in hot-humid climates. Lightweight means generally less material and lower EE: an inherent carbon advantage. But urban buildings today are increasingly of heavy materials, such as concrete and steel. Looking ahead, the challenge of reducing EE is equally relevant for less developed contexts, since urban construction is following similar energy—and carbon-intensive trends all over the world. One can fairly easily reduce EE by up to 50 % in both hot-dry and tropical climates through use of lower EE materials. For many though not all purposes, revitalisation of traditional low-energy materials, in improved forms, is advisable, including non-cement-based masonry and new plant-based biomaterials.

INTEGRATED SOLUTIONS

Since mitigation of energy use and climate emissions is only partly about individual buildings but equally about the overall city planning and energy supply systems, there is a great need to link engineering and architecture with landscape design, urban planning and energy planning. Sustainable solutions demand whole thinking and integrated planning processes. To simplify, one may say that the architect is looking at the individual building, the urban planner only at the overall layout and the energy planner only at issues of energy supply. In energy planning, demand side management

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(DSM) receives increased attention today, but there is still little consideration as to which of our three levels offers the best solutions, or in what combination. Not only the skills but the focus and interests of the actors in these fields are often divergent or even conflicting. We refer to the issue of integration at several points in the book.

There are many synergy effects to be achieved by seeing building, urban layout and city energy system in conjunction. And we should not confine our view to the city limits. As has been illustrated in an Ecocity Master Plan developed by GAIA architects for another Asian context, Taiwan, there are synergy effects to be realised by integrating a city and its hinterland (Butters 2013; Bokalders and Block 2007). In regard to city cooling, it is mainly environments outside the city itself—air, river or others—that are the recipient or heat sink for the large quantities of waste heat that arise when producing energy including district cooling to the city. The surrounding countryside, our source of food, energy, water, wastes treatment and recreation—and cool fresh air—must be understood and revitalised as integral part of a total eco-social system. This must be the paradigm for sustainable human settlements. There is really no such thing as a 'sustainable city', a term which we argue is in some ways an oxymoron (Butters 2013; Cheshmehzangi 2016).

This is another reason why we have combined design practice, research, planning and policy in this book. The specialist approach often leads to missed opportunities. The relatively new area of 'Industrial Ecology' is an example of holistic planning, where industries and other functions are co-located and planned so that both the by-products and waste energy streams from each part are used as resources in others. As will be shown in Chap. 11, some district energy systems in countries like Malaysia are examples of this integration.

Some Underlying Issues

Sustainable city development demands broad vision; the topic of urban cooling ties in with several quite complex and interconnected questions.

Energy and Poverty

As noted, it is the low-income groups who risk being especially disadvantaged in the hot megacities. There is some conflict between two equally valid policy goals: *reductions of energy use and climate emissions* on the one

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hand, and *poverty alleviation* on the other. Absolute reductions in energy use or climate emissions cannot be demanded of the poor. The rich can reduce their footprint, by efficiency gains and reduced consumption; but the poor need access to *more energy*—more cooling as well as more space, lighting, transport, and public services. The greatest growth in energy use and climate emissions is in the low- to middle-income segment of the upwardly mobile urbanising populations. This tendency is worldwide and likely to persist; hence, our topic is of growing relevance in the near future for less developed countries too. Must the new urbanising millions follow a conventional development path, in unhealthy conditions in conventionally designed cities, towards the excessive energy and resource use of the rich? Can we reduce this coming growth in energy use? Our energy/climate goal must be largely preventative; not *absolute reductions*, but *avoided future impacts* of these cities.

Context, Technology and Behaviour

Second, energy including space cooling is relative to socio-economic factors. Whilst the rich in all countries tend to have similar energy amenities, low-income groups may still have no energy amenities at all. Hence, our focus will depend on the particular city context, both climatic, socio-economic and cultural. In terms of needs and equity, the poor are most important. Priorities for energy policy, planning and buildings depend on specific socio-economic conditions in the urban districts in question. Similarly, there is wide recognition today that energy is not just a technical matter, but a socio-technical one. Energy behaviour—such as the much-discussed rebound effect, and even 'prebound effect' (Sunikka-Blank and Galvin 2012)—is increasingly in focus; many energy-efficiency programmes are not achieving the calculated results due to behavioural factors. Poorly chosen solutions may result in high energy use due to such factors despite being technically very efficient. This signals the need for a major shift in energy-policy approaches, to a better balance between the technical and sociological aspects; again a question of cross-disciplinary understanding and integration.

Defining Comfort

Third, indoor environment and thermal comfort are defined in differing ways. It is well known that 'advanced' norms and standards, such as those of

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the World Health Organisation (WHO) or the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), most of which were developed in the West, are not always applicable in hot climate cultures—where higher temperatures and humidity may be perceived as comfortable (Wang et al. 2010). Those are 'high end' norms, which imply high energy use and will, in addition, be unrealistically costly to achieve in many developing country contexts. Given the lack of resources in much of the Asian context, if we insist on absolute norms then the poor are likely to stay as hot and uncomfortable as they are for many years to come. In the poorer cities or typical slum contexts, which have neither energy access nor money, our primary goal should rather be a pragmatic one: to *improve* indoor (as well as outdoor) thermal conditions significantly, but without added costs; not necessarily to achieve the unrealistic goal, at least in the short term, of *absolute* standards or absolute reductions in climate emissions.

Research and the Real World

Finally, there exists a large body of scientific and research literature on cities and urban energy. However, many of the specialist scientific publications are not open access and are seldom read outside academic circles. Knowledge on passive cooling has been around for several decades but is seldom being applied in contemporary city planning. This underlines a frequent disconnect between research and reality. Much research is very theoretical too, whereas there are quite simple principles and solutions available, requiring little more than awareness and knowledge, which can be applied today by city authorities and planners. Hence the need for a pragmatic approach; ideal solutions are seldom attainable in the real world of cities. The need is not so much for technical innovation as for dissemination and delivery of tried and known solutions.

We now turn to nine selected case studies across the hot climate zones of Asia, three on each level of micro, meso and macro considerations towards cooler cities.

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Author Queries

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