CITY Weathers

meteorology and urban design 1950-2010

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Edited by
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& Brian Webb

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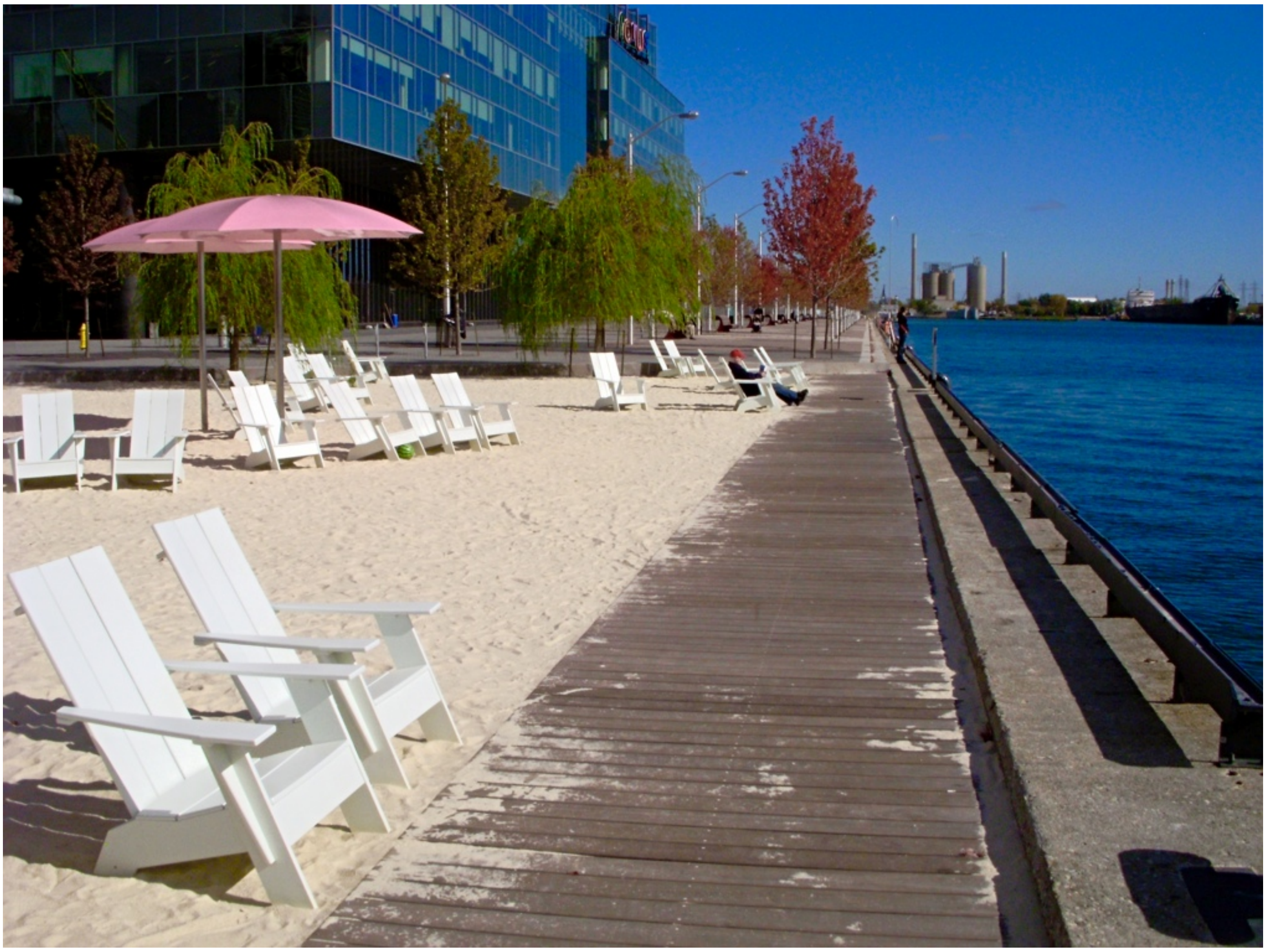
Views expressed in all contributions are those of the authors.

Further information about the ESRC sponsored workshop, participant power points and the Climate Science in Urban Design: A Historical and Comparative Study of Applied Urban Climatology research project can be found online at:

http://www.sed.manchester.ac.uk/architecture/research/csud/



Contents

City Weathers

Michael Hebbert and Vladimir Jankovic

Around midsummer 2011 a group of scientists and practitioners gathered in the country club setting of the University of Manchester's Chancellors Hall to discuss the application of climatology in urbanism. Setting the scene, we recalled the long recognition of the city as environmental singularity – from Greek and Roman interest in layout with respect to prevailing winds and miasmatic swamps, through nineteenth century investigation of industrial pollution and public health, to the contemporary science of urban climates under the menacing shadow of global climate change.

The earliest synthesis of the field was Albert Kratzer's landmark Stadtklima of 1937. With over five hundred references, it brought to attention the wide variety of anthropogenic influences that interact with natural topography and regional climate to shape the urban atmosphere. Kratzer relied upon an extensive array of empirical studies of real cities (mostly German) and their atmospheric qualities by scientists (mostly geographers), a literature strong in local observation but with a limited understanding of process. The field would subsequently take a more theoretical turn as it penetrated the physics of the urban boundary layer, its energy balances and radiation fluxes, the complex fluid dynamics of air-flow over and within built environments, the multilayered microclimates of urban canopy layers defined by building geometry and urban tree cover, and the physiological interface between physical atmosphere and human thermal comfort. Experimental data and numerical modelling grew in significance while the salience of local observational studies declined, and so inevitably did the direct connection with local users. The research community was criticised for retreating into 'a natural science isolation booth' [with] little concern for the relevance their microclimatic fluxes and anomalous precipitation statistics may have to urban planning or quality of life' (Marcus 1979).

The challenge for our workshop was to see how things stand today with applied urban climatology. Arguably we have entered a fresh phase in the relation between the science of urban weather and its applications in everyday urban life. The shift is partly due to global climate change and the growing role of cities in adaptation and mitigation; and partly to the combination of technical innovations such as cheap, lightweight weather stations and automatic data-loggers which have brought down the cost of meteorological observation, and immense increases in computing power for computational fluid dynamics (CFD) modelling, including sophisticated but accessible numerical modelling software such as ENVI-met - all of which, to put it bluntly, leave little excuse for ignorance about the self-induced problems of urban heat islands.

The workshop papers, all available online, map out the contemporary state-of-the-art. Starting from the top, Mark McCarthy (Met Office, UK) discusses the representation of cities in regional weather models and long-term climate forecasts. Urban areas were traditionally left out by meteorologists or treated as localised anomalies within a background climate, but faster computing and improved spatial resolution are bringing them into focus and encouraging the development of new sub-models which realistically incorporate the exchanges of heat, moisture and momentum between urban surfaces and their dynamic atmosphere. So cities and their anthropogenic heat flux - very considerable, as he shows for London - are beginning to be factored in. Meanwhile a similar shift is occurring at the micro scale. Heating and ventilation engineers traditionally focussed narrowly on human comfort within enclosed environments, optimising conditions within the 'cube' and disregarding consequences outdoors in the 'canyon' and the wider urban climate of which it forms a part. Now, as observed by Gerald Mills (University College Dublin), the new interest in building greenery and

Rotterdam, thermal survey by cargo bicycle. Designer: Bert Heusinkveld, Wageningen University

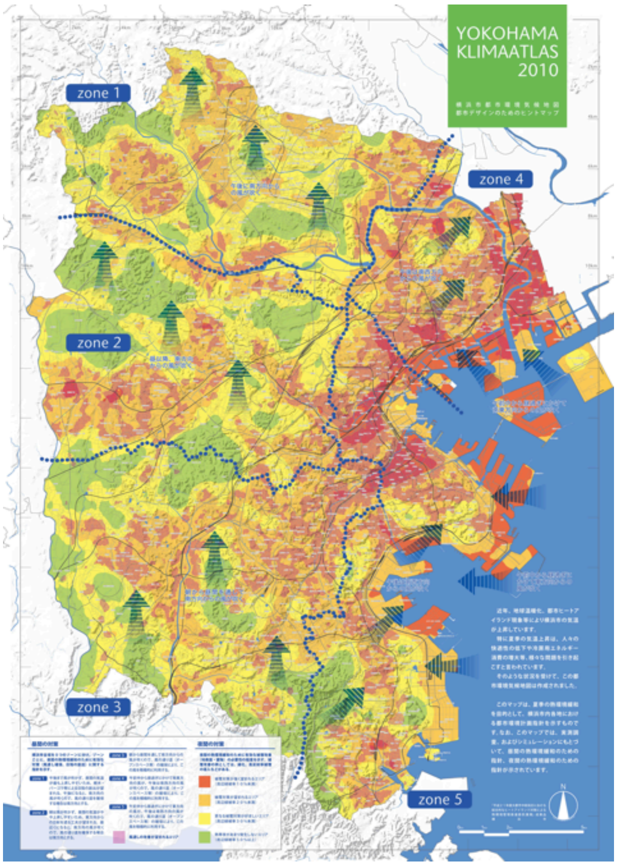
surface albedo is forcefully bringing the indoor and outdoor environments together.

There has been an upsurge in local urban heat island (UHI) research. In the Netherlands the topic had been dropped when studies of air pollution ended in the 1970s. Excess heat deaths in 2003 and 2006 came as a wake-up call. The Dutch realised that they could no longer take for granted their temperate climate and mitigating influence of the North Sea, yet they lacked hard evidence about heat island trends, the national weather stations of the KNMI (Royal Netherlands Meteorological Institute) being located in rural locations, as most are. Bert van Hove (Wageningen University) describes intensive measurement campaigns combining installation of new automatic weather stations, transect surveys with bicycle-mounted data-loggers, and compilation of weather records from hobby meteorologists. Significant urban heat island effects have been discovered, with nocturnal temperature differences between rural and urban areas of up to 7 degrees, and high, though different, variations in the spatial distribution of thermal comfort values (physiologically equivalent temperature or PET measures). Follow-up work is now proceeding on a grand scale with a consortium of 6 Dutch universities, 5 research institutes and 3 international partners under the Climate-Proof Cities programme.

Birmingham City Council's response to the public health and infrastructure impacts of the 2003 European heat wave has been a knowledge transfer partnership with local academic meteorologists. The partners aim to put the city at the forefront of urban climate research, as explained by Richard Bassett (University of Birmingham). They are instrumenting the city with a high-density climate measurement network (HiTemp) as well as setting a new Met-Office standard weather station in the city centre for validation; they have built a digital model of the urban heat island, combining satellite-derived land use data with weather data; and this in turn has been linked to a predictive three-dimensional GIS of the city to create an online planning tool called BUCCANEER, which combines climate variables with social data to give predictive city-wide maps of risk and vulnerability across Birmingham. The user-friendly format allows land-use and model properties to be adjusted to test out 'what if ?' scenarios.

Several contributors focussed on the contribution of greenspace to UHI mitigation. Gina Cavan (University of Manchester) describes the collaboration between the city of Manchester and university-based researchers around three simplified scenarios for future development of the area to the south of the city, based on reducing, maintaining or expanding the existing proportion of green cover. They estimate that the impact of these different strategies could increase or reduce future summer temperatures by about 5°C either way. A study by Oded Potcher (Tel Aviv University, Israel) deconstructs the concept of greenspace, highlighting the different performance of grass and trees in the hot dry climate of desert cities. Detailed comparison of streets with and without trees in the city of Beer-Sheva shows their huge UHI mitigation effect, both giving shade and mitigating temperature through evapo-transpiration; likewise trees in parks, whereas grassed lawns are found to make little contribution to thermal comfort. Jennifer Cox (City University of New York) confirms this withe her analysis of the urban heat islands of low-density suburbs in the State of New Jersey, 60 miles south of Manhattan. Her research compares the lot size requirements of each locality with their land use and vegetation cover. She finds that the codes applied by local municipalities may have originated in garden city idealism but their cumulative effect today is to enlarge the sprawling outer metropolitan heat island of bare asphalt and grass.

Professor Sue Grimmond of King's College London closed the first day's proceedings with a keynote paper, 'Historical and Contemporary Perspectives on London's Urban Climate'. She sets out an entire panorama of scientific enquiry from the earliest measurements of air quality, wind, pressure and temperature to current investigations in which she has a leading part. Landmarks on the way include Luke Howard's early nineteenth century studies of temperature differences and Tony Chandler's heroic 1960s monograph mapping the contours of the urban heat island within the Metropolitan Green Belt. Despite the closure of the London Weather Centre in 2010 today's city has a more extensive weather measurement network than ever before, thanks to low cost sensors and automatic data transmitters, and the policy stimulus of the Greater London Authority's statutory responsibility for environmental management.



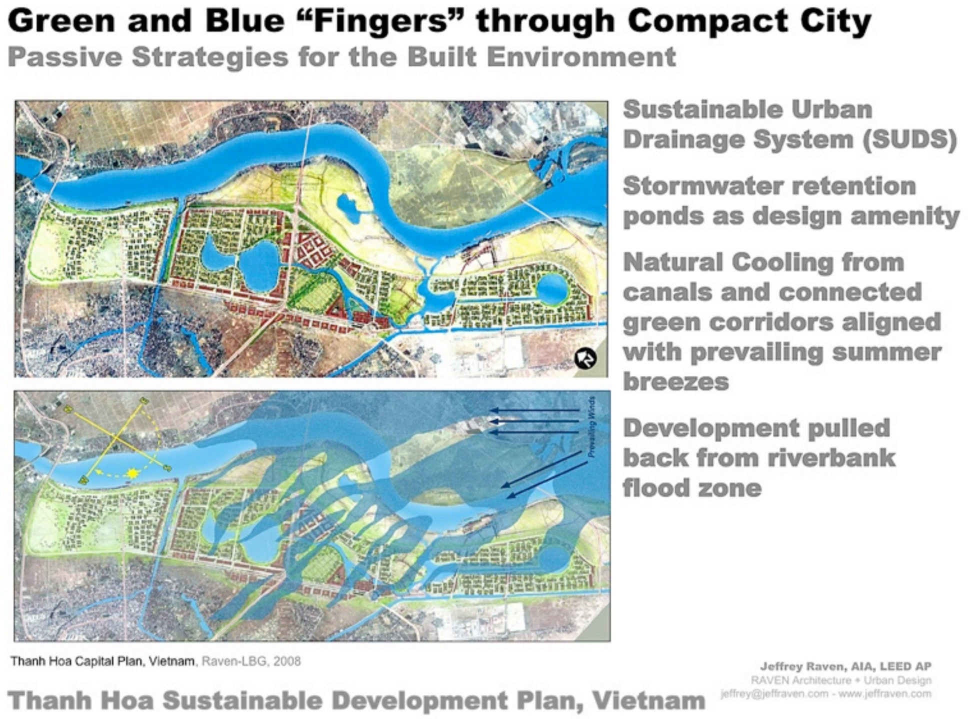
Yokohama, Klimaatlas 2010. Image, Yokohama City Council

Workshop participants enjoyed a late-night screening of the famous documentary on climatic design in the city of Stuttgart, featured as the West German Government's exhibit for the 1976 UN-Habitat conference in Vancouver. It shows how the postwar city tackled its air quality problems through tangible design policies based upon systematic meteorological research. This historic piece of sustainable development propaganda was introduced by Dr Jürgen Baumüller, Stuttgart's former head climatologist, now retired. In the concluding keynote of the workshop his successor Dr Ulrich Reuter described the city's continuing active practice of meteorological observation and monitoring, and its most significant contribution to urban design, the 'climate atlas'. Reuter introduced the Klimaatlas of 1992 and explained how it had been updated and expanded in 2008 to cover the entire metropolitan region. By this means, climate management has been incorporated into every scale of planning, from strategic greenspace protection to site layout, landscaping and detailed building design.

Stuttgart is important precisely because it is not a one-off - its methodologies have been widely tried and tested elsewhere. Lutz Katzschner (University of Kassel, Germany) emphasizes its general applicability in response to the challenge of thermal stress in cities. His paper describes climate mapping for Kassel and Frankfurt as well as an experimental interactive table-top flat-screen Klimaatlas for Arnhem in the Netherlands, where prospective designs for the UHI can be sketched and tested for their effects on the microclimate.

Chao Ren (Chinese University of Hong Kong) traces the impact of the Klimaatlas from these Northern European origins to present-day applications in more than twenty countries. Her paper shows how the technique spread through Germany and was consolidated into a national engineering guideline, and then, remarkably, was transferred from low density cities in a temperate inland climatic region, to high density tropical urbanism on the SE Asian Pacific Rim. Climate mapping and design of wind-paths – kaze-no-michi – is widely applied in Japanese cities, though it's far from clear they have the ability to do anything about the causes of summer UHI increase. Edward Ng (Chinese University of Hong Kong) describes the impressive case of Hong Kong where the issue of urban climatic quality leapt into prominence as a result of the 2003 SARS epidemic. It became clear that the city's heat problem had been massively aggravated by the blocking of natural street-level ventilation by high-rise development. Permissive building regulations had allowed unbroken walls of waterfront apartments to seal off sea breezes, penalising the old and the poor who live at lower levels of stifling street canyons. Externally mounted air conditioning units add to the outdoor heat burden. Professor Ng has deployed field surveys of thermal comfort, wind tunnel modelling, GIS mapping and numerical CFD simulation in a scientific campaign to raise awareness of Hong Kong's ventilation crisis. The University prepared its own urban climate atlas of the island with detailed recommendations for building height and setback in the most affected zones. Only with a

Hong Kong, the campaign for fresh air. Image, Professor Edward Ng, Chinese University of Hong Kong



Green and Blue “Fingers” through Compact City

Passive Strategies for the Built Environment

Sustainable Urban Drainage System (SUDS)

Stormwater retention ponds as design amenity

Natural Cooling from canals and connected green corridors aligned with prevailing summer breezes

Development pulled back from riverbank flood zone

Thanh Hoa Capital Plan, Vietnam, Raven-LBG, 2008

Thanh Hoa Sustainable Development Plan, Vietnam

Jeffrey Raven, AIA, LEED AP
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Thanh Hoa, Vietnam: “Green and blue fingers” - contiguous green corridors and canal circulation networks aligned with prevailing sea breezes, punctuated by storm water retention bodies as urban design amenities; image, Jeffrey Raven – Louis Berger Group Thanh Hoa City by 2020, Vietnam (2008)

robust evidence base could the planning argument be won. Ng's forceful lobbying helped to put the outdoor environment onto the political agenda, bringing a revision of planning codes to enforce building separation, and a proactive use of climate mapping techniques by the Hong Kong government in initial planning for redevelopment of the former Kai Tak airport site.

Several other participants describe applications in hot humid and hot dry cities. Sascha Henninger (University of Kaiserlautern, Germany) uses the ENVI-met microclimate model to optimise the layout of a dense housing complex in the monsoon-belt tropical environment of the city of Daegu, South Korea, adjusting building form, layout and tree-planting to get the best ventilation from prevailing winds along the river valley and local air exchange within the immediate neighbourhood. Evyater Erell (Ben-Gurion University, Israel) describes the application of simple climatic rules to two projects in the Negev desert: a housing scheme with narrow shady north-south pedestrian alleys and wider east-west vehicle woonerfs so no-one's solar access is blocked; and a shopping centre with colonnades, trees, canopies and fountains. No complex modelling here, just appreciation of local context and design based on a sound grasp of the basic science (Erell 2011).

Jeffrey Raven (Raven Architecture + Urban Design, New York City) discusses designs for the Thanh Hoa Capital Plan (Vietnam) and Kolkata Green Satellite Development (India), showing how they make the most of sun wind and rainfall to promote resilience. From his own experience as an environmental architect and urban designer he argues that outdoor climate must be incorporated into sustainability rating systems - BREEAM, LEED, the STAR Community Index. Of course, the human factor remains, as Hadas Saaroni and Tali Hatuka (Tel Aviv University) remind us with the paradoxical tale of a park development on the Tel Aviv waterfront. The grass has to be irrigated from the drinking water supply and there are complaints about the lack of shade. The climatological advice at the design stage was that the space should be landscaped with trees: nevertheless an open park was what users demanded, and got.

Rohinton Emmanuel (Glasgow Caledonian University) summarises the vital importance of urban climatology for designers in the global south. The world's fastest growing cities are in the tropics, and local warming doubles the impact of

Planning actions to be taken

Maßnahmen Nordend
Verortung der Planungsempfehlungen

Manchester June 2011

Frankfurt, point-specific design recommendations based upon high-resolution climate analysis. Image, Professor Lutz Katzschner, Kassel University

global climate change. When temperatures are close to human tolerance thresholds, every degree of mitigation matters. Too few decision-makers appreciate the importance of outdoor comfort and the availability of viable remedies to promote shade, encourage natural ventilation, provide greenery and enhance surface albedo (as a footnote Rohinton warned that they need to be the right kinds of trees, opening their stomata by day; and the right sort of albedo treatment: phase change materials [PCM] rather than white paint). Expertise remains scarce but the costs of data collection, modelling and monitoring the urban climate have never been more affordable. As Ng (2011) argues, every city should want this knowledge.

Setting up the workshop we invited historical papers. In the event we only got two. Katja Eßer (RWTH, Aachen University, Germany) presents her investigation into the history of nineteenth century urban climate changes as the spa city of Aachen built over its back gardens, densified and industrialised with textile and mechanical engineering works, overwhelming the traditional supply of fresh air from adjacent hills. It was a fascinating example of historical analysis undertaken as part of a contemporary interdisciplinary survey of built form, climate and health in the central-European city. Csilla Gal (Illinois Institute of Technology, USA) traces the history of Budapest housing design from dense 19C courtyard blocks into early 20C perimeter blocks with large internal gardens, to be followed after 1950 by Zeilenbau freestanding blocks aligned north-south, and they in turn by hybrid podium and tower typologies. She shows how each phase of design was influenced by generic considerations of light and air but urban climatology played only a fleeting role. Current heat-waves are likely to change that.

The City Weathers workshop reached clear conclusions. Climatically responsive urban design requires local investigation. Generic environmental measures (building performance standards, carbon inventories, emissions limits, greenspace targets) go so far but like oral medicine in a human body they may not touch the spot. Cities are spatial entities and effective medication sometimes needs to be topical, applied just where it matters. The climate atlas is the X-ray that reveals the invisible atmospheric ecology of the urban heat island, its climatopes, hot-spots, pollution sumps, rain pockets, cold air production zones and drainage slopes. Urban climatology provides the evidence base for point-specific design response. With examples of good practice from around the world, the workshop showed that the message of UN-Habitat's 1976 documentary is getting through at last.

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REFERENCES

Erell E, Pearlmutter D, Williamson T (2011) Urban Microclimate – Designing the Spaces Between Buildings London: Earthscan

Marcus M (1979) ‘Coming full circle: Physical geography in the twentieth century’ Annals of the Association of American Geographers 69 (4): 521-532.

Ng E (2011) 'Towards planning and practical understanding of the need for meteorological and climatic information in the design of high-density cities: a case-based study of Hong Kong' International Journal of Climatology [article first published online http://onlinelibrary.wiley.com/doi/10.1003/joc.2237]

Including Cities in Climate Models

Mark McCarthy

1. A Climate Research Perspective

The urban climate modification noted by Luke Howard in the early 19th Century is contemporaneous with the conceptual leaps made by Joseph Fourier to recognise that the atmosphere traps thermal radiation. While Fourier cited earlier 18th century experiments that had demonstrated the same principle with glass, and Howard recognised the localised urban nature of the temperature anomalies he observed, these seminal works of nearly 200 years ago have paved the way for the enduring analogies of the greenhouse effect and urban heat island respectively. A persistent paradigm that has also endured to some extent is that the urban micro-climate, and specifically the urban heat island effect, is considered an artificial feature distinct from the ‘background’ climate.

In the latter part of the 20th Century it was recognised that emissions of greenhouse gases (GHG) through fossil fuel combustion and land use change have a significant influence on global climate. A majority of global primary energy demand is urban and consequently the influence of urbanisation on global climate is included in contemporary climate model projections indirectly through the socio-economic scenarios that underpin the projected GHG emissions (Nakićenović, 2000), but urban land use is still currently a tiny fraction of the available land surface of the Earth and therefore generally ignored as a large-scale forcing. Consequently the climate change literature contains very limited consideration of the urban environment (IPCC, 2007) with a focus primarily on ensuring urbanisation has not unrepresentatively influenced the record of historical land near surface temperature (e.g. Karl et al. 1988, Parker, 2010). Emerging research is however demonstrating the potential feedback on the regional and continental scale of urban activity (e.g. Trusilova et al. 2008, Flanner, 2009) and the climate change the majority of the world population will experience in the 21st Century will be through the cumulative impacts of global effects of GHG emissions and local/regional urban effects.

An ever increasing demand on climate science is to provide the scientific advice suitable for informing the development of adaptation and mitigation policy, nationally and regionally. To support the ever growing urban population of the world vast urban development must occur over the coming century on a timescale over which significant climate change is projected. For regions in which the population is already heavily urbanised, the challenges of adapting society to climate change are heavily concentrated within the urban environment. When thinking about the potential impacts of climate change on urban areas traditional descriptive assessments of urban microclimates that present urban anomalies above a background climate state may ignore how the changing climate might itself perturb the physical processes that yield the observable heat island effect. Similarly adding climate change projections to an urban ‘background’ state ignores how the urban surface properties and future urbanization might perturb the local or regional evolution of greenhouse gas induced climate change.

This paper outlines some contemporary ways in which urban processes are being incorporated directly into climate models and their utility in making more informed urban climate projections. The examples presented all relate to the Met Office Unified Model and its land surface scheme, but this is not a unique tool (see for example Masson, 2000, Oleson et al. 2008, Grimmond et al. 2010)

2. Cities in the climate model

The Met Office Unified Model (UM, http://www.metoffice.gov.uk/research/modellingsystems/unified-model) and the off-line surface scheme that constitutes the Joint UK Land Environment

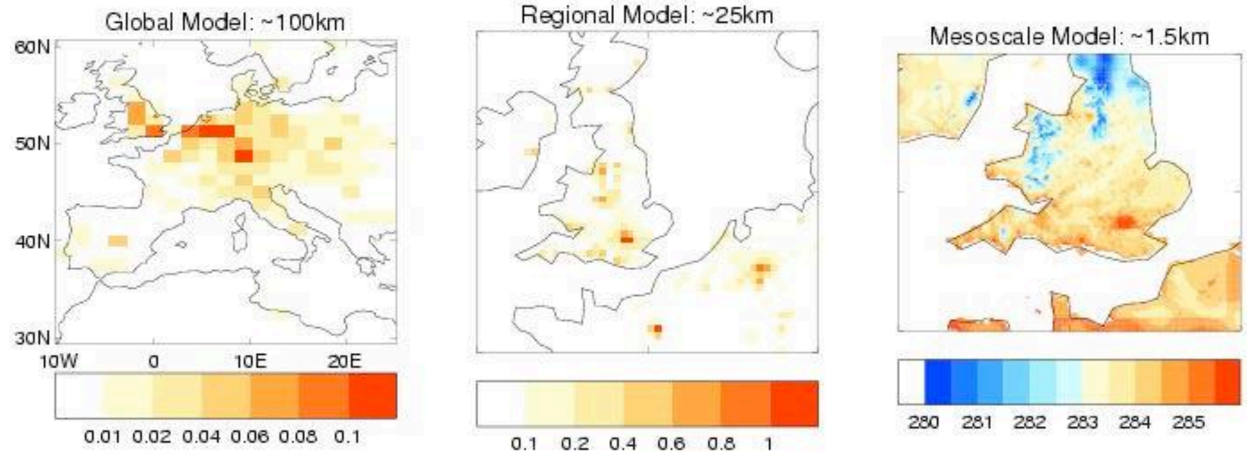

Figure 1: (Left) Increase in grid cell mean temperatures (K) of the urban land surface for a small region of a 20-year run of the global climate model at 1.875o x1.25o grid resolution. (Centre) The same for the regional climate model at 0.22o x 0.22o grid resolution on a rotated pole grid. Note the change in scale between left and centre plots. (Right) Absolute temperatures (K) simulated for a 1-year (1995) simulation of the mesoscale model. A small sub-region of the full model domain is presented in the case of the global and regional models.

Simulator (JULES, http://www.jchmr.org/jules/) currently include a simple parametrization of the thermal and aerodynamic properties of the urban land surface outlined in Best (2005) and evaluated in Best et al. (2006) with the intention of better evaluating the interactions of the urban surface with larger-scale climate forcings.

This scheme is now being upgraded to include a more sophisticated scheme described in Porson et al. (2010). The model provides better representation of key surface properties to give more realistic exchanges of heat, moisture and momentum between the dynamical atmosphere in the UM and the urban land surface. The utility of simple urban parametrizations within coarse grid climate models has been documented in McCarthy et al. (2010), Oleson et al. (2010), and McCarthy et al. (2011).

The UM and JULES provide scope to explore urban climate interactions across space and time scales. Figure 1 demonstrates the resolution of the global (GCM), regional (RCM), and meso-scale version of the climate model. At the global model scale all but a few isolated grid cells across the world are warmed by more than 0.1oC as a result of including the urban land surface. At the regional model resolution significant feedbacks from the urban land surface are detectable in excess of 1oC for large cities, in this example London, Paris, and the Rhein-Ruhr region having the greatest impact, but smaller cities in the UK such as Birmingham, Manchester, and Glasgow are also evident.

The meso-scale model at 1.5km resolution captures the small-scale topographic features and resolves larger towns and cities. In contrast to the GCM and RCM examples the meso-scale run is presented as absolute temperatures rather than a temperature difference. In understanding potential impacts of climate change, one must consider not just the urban micro-climate but how it relates to and interacts with the surrounding regional climate.

Present day urban cover has little measureable feedback at the GCM scale, but there are numerous benefits to including an urban parameterisation within such a coarse-grid model. The coverage of the model allows for regional sensitivities to be explored in relation to climate forcings from both greenhouse gases and urbanisation, and with the urban scheme an intrinsic part of the surface exchange it will respond to the simulated weather at every model time step through long integration climate scenarios across all simulated climate regimes. This allows for some capacity to explore the impact of climate variability on urban extremes, and also to explore regional sensitivities to increased urbanisation, i.e. controlled experiments that compare which world climate regimes are

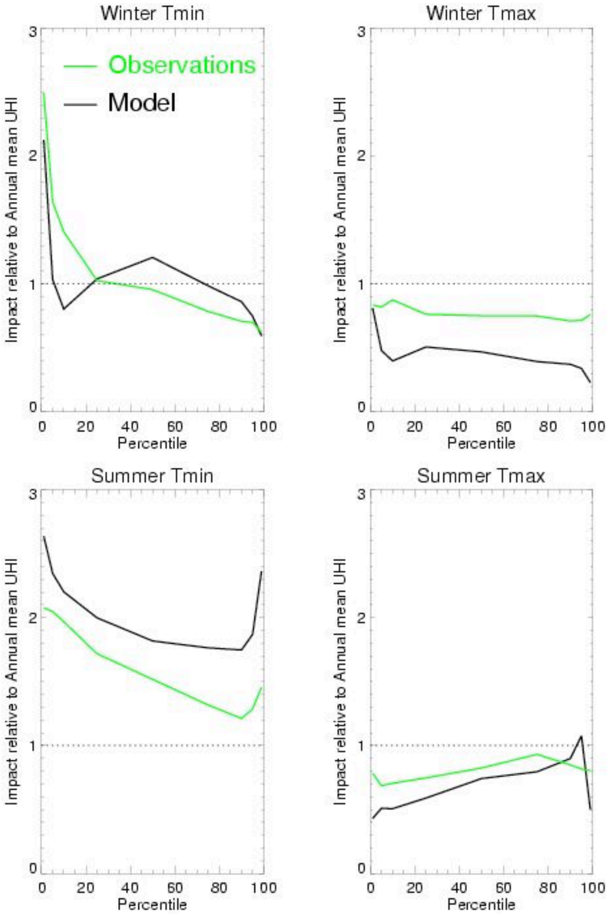

Figure 2: A comparison of estimates of the UHI magnitude relative to the annual mean UHI from observations (green, Perry and Hollis, 2005) and a regional climate model experiment (black, McCarthy et al. 2011). The y-axis shows the dimensionless ratio of UHI strength to annual mean UHI for the 1st ,5th ,10th ,25th , 50th ,75th ,90th ,95th , and 99th percentile of (left) Tmin and (right) Tmax temperature distributions for (upper) winter and (lower) summer seasons.

most at risk of supporting large urban heat islands both now and in the future.

In terms of urban climate extremes Figure 2 compares the impact of the urban heat island on the present day temperature distribution of London in the RCM with observations scaled to the RCM grid (Perry and Hollis, 2005), and normalised to the annual mean urban heat island magnitude. Values above 1 represent heat islands greater than the annual average, and below 1, heat islands smaller than average.

Overall the heat island has greatest impact in summer and during the night for both model and observations, although this configuration of the model has a tendency to overestimate the heat island during summer. Both model and observations also show the greatest heat islands are occurring on the coldest nights (1st and 5th percentiles), which most likely reflects situations of strong nocturnal radiative cooling that is being strongly damped by the urban environment. Although a secondary peak is also evident for the warmest (95th and 99th percentile) summer nights. In contrast the summer Tmax heat islands tend to be larger on warmer days. This serves as a reminder that the urban heat island magnitude in isolation is not a useful gauge of the potential impacts of urban climate change, which will be most strongly felt during extreme events. An extreme heat island event during relatively cool conditions will be less significant for human comfort than a small heat island during a heat wave for example.

3. An example application for UK Climate Projections

The UK Climate Projections (UKCP09, Murphy et al. 2009) provide a state-of-the-art methodology for creating high resolution probabilistic projections of climate change for the UK. This method utilises results from a suite of simple energy balance climate models, GCMs and RCMs. The UKCP09 projections are provided at the ~25 km resolution of the RCM. However, the climate modelling in UKCP09 does not account for the role of the urban land surface directly (Annex 7 of Murphy et al., 2009). As a contribution to the EPSRC (www.epsrc.ac.uk) funded programmes SCORCHIO and ARCADIA (http://www.ukcip-arcc.org.uk/content/view/587/9/) one of the eleven-member RCM ensemble used in UKCP09 was repeated to include the urban surface exchange scheme of Best (2005) encompassing all regions across UK, Europe and parts of North Africa. We also ran the JULES off-line version of the same urban scheme driven by all 11-members of the UKCP09 ensemble for London. The results are summarised in Figure 3 showing 30 year running means of the evolution of the UHI across the 11—member ensemble. The fully coupled RCM experiment is highlighted in red. The timeseries represent the difference in warming between the simulations with and without urban surface. The 1.5m air temperature is reasonably well constrained, and the urban and non-urban simulations agreeing to within 0.1°C consistent with analysis of 20th century climate change in

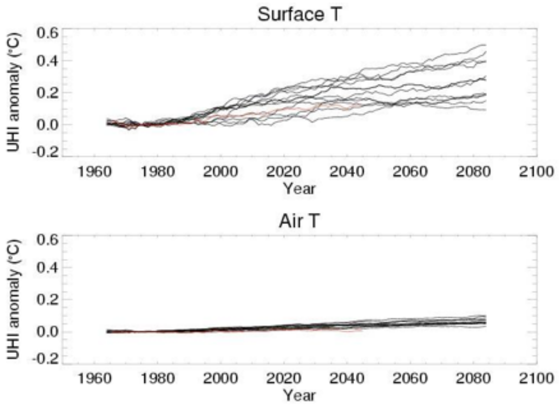

Figure 3: 30-year running mean timeseries of (upper) surface and (lower) 1.5m air temperature urban heat island anomaly relative to the 1971-1990. Results are shown for (black) an 11-member ensemble of the off-line JULES urban model, and (red) a fully coupled urban-RCM experiment.

London from observations by Jones and Lister, 2010. The UKCP09 projections are based on air temperature, and therefore the inclusion of the urban surface is not expected to significantly modify those UKCP09 projections.

However, additional increases in the surface temperature of the urbanised simulation result from differences in the way that the urban and rural energy balances respond to the changes in the radiative forcing through the simulation. The air temperature response appears to be consistent for urban and rural situations, but there are potential implications for the urban built environment from surface energy balance changes that result from climate change that would not be captured by air temperature projections alone.

4. Urban energy use as a climate forcing

Energy use within the urban environment will contribute to the burden of GHGs in the atmosphere as discussed previously. However the waste heat from energy use emitted to the environment is also a well recognised contributing factor to the urban heat island (Sailor, 2011). The demand for energy is also strongly influenced by the heating and cooling requirements of buildings making this additional anthropogenic heat flux (AHF) both a potential forcing and feedback to urban climate change. The Met Office climate model currently considers only a prescribed forcing term from AHF, but other models (e.g. Oleson et al. 2008) can calculate the building heating and cooling loads directly.

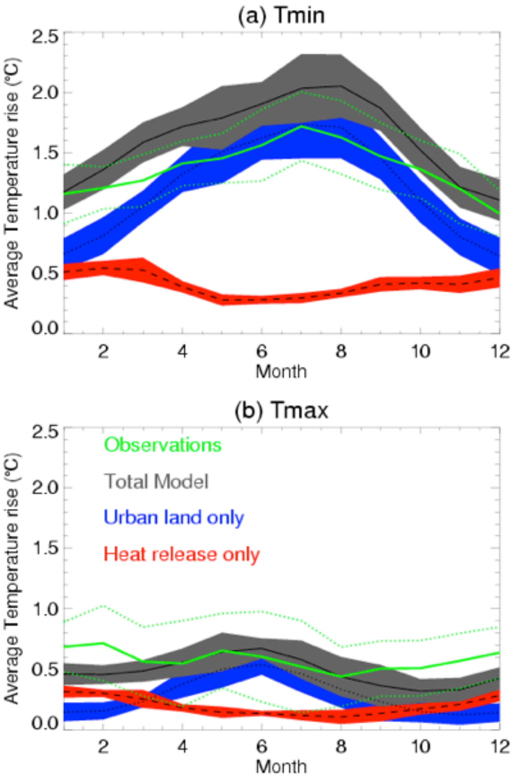

Figure 4: Annual profile of the RCM (McCarthy et al. 2011) and observed (Perry and Hollis, 2005) estimates of the city-scale urban heat island for central London grid cell separating the urban land and AHF contributions for (upper) Tmin and (lower) Tmax. Coloured shading (grey, blue, red) represent the 95% confidence interval.

Globally the present day AHF equates to a net forcing of about 0.03 W m-2, but locally it is much more significant, Allen et al. (2011) estimate peaks in excess of 100 W m-2 for a number of global megacities. The inclusion of present day estimates of AHF (Greater London Authority, 2006) as an additional term in the surface energy balance of the RCM yields an estimate of approximately 30% of London's city-scale nocturnal air temperature heat island, proportionally greater in winter than summer and summarised in Figure 4.

Continental to global scale forcing from AHF should be determined from primary energy demand projections rather than final consumption in order to include the total heat release from burning of fossil fuels. From the projections of world energy demand generated for the high-end scenario for the Fifth Assessment Report of the IPCC (AR5) suggests an average heat flux of 24 W m-2 for 2005 over 585,754 km2 or 0.1% of the globe rising to 31 W m-2 across 1,652,860 km2 or 0.3% of the globe by the year 2100, equating to a global forcing of 0.03 W m-2 rising to 0.10 W m-2 by 2100, or 0.27 W m-2 rising to 0.34 W m-2 averaged over land, but with much higher local and regional forcings with the potential for continental scale climate impacts (Block et al., 2004, Flanner, 2009).

Therefore the potential for regional climate forcing from urban energy use, and the potential for urban heat island mitigation to influence climate and energy use should account for this small but significant source of anthropogenic climate change in addition to the larger contribution to warming made at the city-scale and future integrated assessments might consider the important interactions between climate and energy use in the urban context.

5. Concluding remarks

Advances in the fields of urban meteorology and climate research have resulted in an emerging capability to quantitatively explore the interactions of urban-scale processes and large-scale radiatively forced climate change within the constructs of the dynamic numerical climate models. The ever-increasing resolution of these models, and the emergence of high-resolution probabilistic projection methods such as UKCP09 mean that the urban environment can no longer be ignored in the context of the suite of available climate models.

Recent collaborative projects within the UK (http://www.ukciparcc.org.uk/content/view/587/9/) have explored methods for best utilising such information to complement much finer resolution neighbourhood scale assessments of vulnerability and risk in the urban context.

REFERENCES

Allen, L., F. Lindberg, and C.S.B. Grimmond, 2011: Global to city scale urban anthropogenic heat flux: model and variability. Int. J. Climatol. online first, DOI: 10.1002/joc.2210

Best, M.J., 2005: Representing urban areas within operational numerical weather prediction models. Boundary-Layer Meteorology, 114, 91-109

Best, M.J., C.S.B. Grimmond, M.G. Villani, 2006: Evaluation of the urban tile in MOSES using surface energy balance observations. Boundary-Layer Meteorology, 118, 503-525

Block, A., K. Keuler, and E. Schaller, 2004, Impacts of anthropogenic heat on regional climate patterns. Geophys. Res. Letts. 31, DOI: 10.1029/2004GL019852

Flanner, M. G., 2009: Integrating anthropogenic heat flux with global climate models, Geophys. Res. Lett., 36, L02801, doi: 10.1029/2008GL036465.

Greater London Authority, 2006: London Energy and CO2 Inventory (LECI) 2003. Greater London Authority, London

Grimmond, S. et al., 2010: The International Urban Energy Balance Models Comparison Project: First results from Phase 1, J. Applied Meteorology and Climatology, 49, DOI: 10.1175/2010JAMC2354.1

IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H. L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Karl TR, Diaz HF, Kukla G., 1988: Urbanization: its detection and effect in the United States climate record. J Clim, 1, 1099–1123. DOI: 10.1175/1520-0442

Jones PD, Lister DH., 2009: The Urban Heat Island in Central London and urban-related warming trends in Central London since 1900. Weather , 64, 12, 323-327.

Masson, V., 2000: A physically-based scheme for the urban energy budget in atmospheric models. Boundary-Layer Meteorology, 94, 357-397

McCarthy, M.P., M. J. Best, and R. A. Betts, 2010: Climate change in cities due to global warming and urban effects. Geophys. Res. Letts. 37, L09705, doi:10.1029/2010GL042845

McCarthy, M.P., C. Harpham, C. Goodess, and P. Jones, 2011: Simulating climate change in UK cities using a regional climate model, HadRM3. submitted to Int. J. Climatol.

Murphy, J.M., D.M.H. Sexton, G.J. Jenkins, B.B.B. Booth, C.C. Brown, R.T. Clark, M. Collins, G.R. Harris, E.J. Kendon, R.A. Betts, S.J. Brown, K.A. Humphrey, M.P. McCarthy, R.E. McDonald, A. Stephens, C. Wallace, R. Warren, R. Wilby, R.A. Wood 2009: UK Climate Projections Science Report: Climate change projections. Met Office Hadley Centre, Exeter, UK

Nakićenović, N., and R. Swart (eds.), 2000: Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 599 pp.

Oleson, K.W., G.B. Bonan, J. Feddema, M. Vertenstein, C.S.B. Grimmond, 2008: An urban parameterization for a global climate model. Part I: Formulation and evaluation for two cities. J. Appl. Meteorol. and Climatol. 47, 1038-1060

Oleson, K.W., G.B. Bonan, J. Feddema, and T. Jackson, 2010: An examination of urban heat island characteristics in a global climate model. International Journal of Climatology, doi:10.1002/joc.2201.

Parker, D.E., 2010: Urban heat island effects on estimates of observed climate change, Wiley Interdisciplinary Reviews: Climate Change, DOI: 10.1002/wcc.21

Perry, M., and D. Hollis, 2005: The development of a new set of long-term climate averages for the UK, Int. J. Climatol., 25, 1023-1039

Porson, A., P. A. Clark, I. N. Harman, M. J. Best, and S. E. Belcher, 2010: Implementation of a new urban energy budget scheme in the MetUM. Part I: Description and idealized simulations. Q. J. R. Meteorol. Soc., 136, 1514-1529

Sailor, D., 2011: A review of methods for estimating anthropogenic heat and moisture emissions in the urban environment, Int. J. Climatol., 31, DOI: 10.1002/joc.2106

Trusilova, K., M. Jung, G. Churkina, U. Karstens, M. Heimann, M. Claussen, 2008: Urbanization impacts on the climate in Europe: Numerical experiments by the PSU-NCAR Mesoscale Model (MM5), Journal of Applied Meteorology and Climatology, 47, 1442-1455

Cubes and canyons: Different perspectives on the urban climate

Gerald Mills

The climates created by urban areas have been studied by many disciplines, each of which has a particular perspective. As a broad characterisation, these have been concerned with either indoor or outdoor climates, which for the sake of ease I will refer to as Architectural and Climatological viewpoints. Although both climates are obviously linked to each other, their examination has proceeded along different paths and there has been remarkably little 'cross-over'. As a consequence, a holistic urban climate science has not emerged. The current concern for global climate change and the role of cities offers a fresh opportunity for integrating these perspectives. In this paper I will introduce research as practiced from the indoor and outdoor perspectives, identify their common ground and discuss their roles in dealing with global climate change. To start, I will briefly outline the nature of the urban climate effect.

The urban climate effect: Urban climates are distinctive and are readily observable as a difference in the properties of air (temperature, humidity, wind, etc.) between the urban and surrounding non-urban environments, which result from city form and function. **Form** refers to the material composition and geometry of the city. Cities are constructed of manufactured materials that are generally dense, impermeable to water and their thermal and radiative properties are consistent (unlike natural materials). These materials are shaped to create complex three-dimensional objects that cast shadows, restrict access to the sky and block airflow. Each of these qualities alone would create a distinct near-surface climate. **Function** refers to the host of activities that are concentrated in urban areas and require a constant through---flow of materials and energy. While some of these resources are employed to alter form (e.g. construct new buildings), most is used to sustain these activities and results in the deposition of wastes (degraded materials and energy), including CO2, into the environment. This urban 'metabolism' is responsible for changing the composition of the urban atmosphere. Together, form and function create distinct climates at a hierarchy of scales (Oke, 2006).

At the micro-scale, a myriad of climates are generated in the urban canopy layer, below the average building height (~1-100m). The climate effects at this scale are transferred to the overlying air by turbulence where mixing dilutes individual contributions of walls, roofs, gardens, etc. At a height of about twice the height of buildings the atmosphere has adjusted to these exchanges and has acquired a local- scale urban effect (~1-10km) that reflects the character of the underlying 'neighbourhood'. At an urban scale, these local-scale effects are mixed to create a plume of modified atmosphere that extends downwind of the city. These scale distinctions represent one of the most important outcomes of research and provide a framework for observing and modelling the urban climate effect. They also provide a basis for examining an urban response to climate change.

The indoor perspective: There is a clear design imperative for the indoors, that of creating a climate suited to its functions. For many buildings this requires a climate that is thermally comfortable for its inhabitants by regulating exchanges with the outdoors. Ideally, this can be accomplished through decisions about site location, material selection and the design of the envelope alone. Thus, the most efficient design is one that meets its goals without the need for 'imported' energy (so called 'passive' buildings). The same outcome can also be achieved by separating the indoor from the outdoor climate and overcoming the climate stresses through intensive energy use, the vast bulk of which is derived from fossil fuels. In an urban setting, where there is a desire to maximise the use of land, the former provides a climatic basis for an urban design, whereas the latter does not.

The prominence of passive strategies in indoor research reflects the energy concerns of the time. Its starting point has been the individual building (often represented by a cube form) and its solar radiation receipt (Atkinson, 1912). This building element is used to derive a shadow mask, which is used to organise the layout of other buildings, such that each has access to sunlight (Matus, 1988). Alternatively, building plots are employed to derive a building volume that assures the same outcome (Knowles, 2003). The other urban unit employed in research has been the street and its role in diminishing access to natural daylight in buildings. This concern was incorporated into densely built urban environments through the use of simple geometric guidelines (Kwartler and Masters, 1984).

What marks this research is the concern for the indoor climate of the building, rather than the outdoor urban climate. The intensive use of heating and air conditioning systems has allowed the building to become isolated from the outdoors. Paradoxically, the waste heat from buildings adds to the climate stress that the building was designed to counteract.

The outdoor perspective: Climatology has focussed on the outdoors and the creation of the urban climate. It has two distinct strands associated with air pollution, which developed as a sub-discipline of meteorology, and with general climate, which began largely as a sub-field of physical geography.

Air pollution studies developed rapidly in response to public health concerns about poor air quality in cities. The emphasis in this research has been on the nature of urban functions that give rise to emissions and the solutions have largely been controlling these (e.g. Clancy et al., 2003), rather than altering the urban form. As the nature of urban functions changed so did the focus of research. In the urban context, concern about emissions from vehicles inspired research into the nature of urban form and how it could regulate the emission of transport pollutants into the wider atmosphere (DePaul and Sheih, 1985). Much of what we know of the relationship between street geometry and airflow has accrued from this research.

The study of climates in cities generally was largely descriptive in content well into the mid-1960's. Observations of spatial patterns of air temperature, wind, precipitation etc. in different cities demonstrated the urban effect but did not establish clear links between the nature of urban form and the effect it generated (Lowry, 1977). A feature of this work has been the extensive study of the urban heat island, which describes a warm pool of air that forms over the city at night-time. Over the last forty years the field has become progressively more sophisticated as it adopted both an experimental and a process-based method. Thus, the urban canyon has become an essential tool to understand the formation of the canopy-level heat island. The current state of knowledge on the outdoor climate integrates much of the airflow (air quality) and the energy budget (climatology) research acquired using these research approaches.

The focus of research on common urban forms has provided considerable insight into the nature of the urban effect. However, the majority of this work has been done in the developed cities of the middle-latitudes. There is limited information on other urban forms in other climates and little information on cities globally that would allow a transfer of the knowledge gained.

Common ground: There is a great deal that is comparable across these disciplines. The use of simple forms (cubes and canyons) provides a common platform for linking research at the local-scale. However, there is little evidence that outdoor knowledge is brought to bear in urban planning/design. There are many reasons put forward to explain this including the inherent complexity of the problem and the failure of climatologists to compose guidelines. It is certainly true that little outdoor research has been undertaken from a design perspective. For example, the urban heat island phenomenon has, despite its ubiquity, been considered as of academic, rather than practical significance. While the concern in planning has been on managing solar energy, a great deal of climate research is concerned with a night---time phenomenon. However, I suspect the reason is more prosaic. There has been no imperative, until recently, to consider climate issues in urban design/planning.

The exception has been air quality, which has a health mandate and could be addressed by managing urban functions, rather than form. While the urban effect is unambiguous it has not been considered of sufficient relevance. This is likely to change as energy concerns (directly and indirectly) move to the fore once more. In these circumstances, design strategies must reassert the links between the indoor and outdoor as part of a broader engagement with the urban climate. This will require a coherent approach to managing the outdoor climate that focuses on form and function at a hierarchy of scales. Whereas, individuals experience climate stresses at the micro- and local- scales that require design interventions, these should be done within a grander urban-scale strategy that looks at issues of built density, urban extent, the spatial organisation, etc.

The future: There are two concurrent processes that will bring indoor and outdoor urban issues together forcefully (Mills, 2007). Firstly, a growing proportion of the global population live in urban areas. The transition from 'rural' to urban has already happened in the economically developed parts of the world where much of urban form including the physical extent of the city and its attendant infrastructure, is in place. For these places the degrees of freedom for re-design is somewhat limited. By contrast, the rate of transition in the less developed part of the world is intense and new cities are being built. While the cities of the developed world will have to be 'retrofitted', those that are newly emerging have the potential to become different types of cities. Secondly, there is a growing recognition that the drivers of anthropogenic climate change (chiefly the emission of CO2) are linked to urbanisation (and development) and that cities are especially vulnerable to the effects any changes, owing to both their locations and infrastructural investment. One area that has received considerable attention is the impact of both predicted global warming and of the urban heat island on public health.

Not surprisingly, the global response strategies (mitigation and/or adaptation) have been mapped to urban scales. Mitigation refers to approaches that regulate the functions that generate the emissions of CO2. Adaptation accepts that climate change will occur and focuses on altering urban form in response. Of course, the two could be related – modifying urban form could be used to regulate urban metabolism. However, a simple translation of strategies based on global concerns to urban scales may not be correct or appropriate.

Two of the strategies for dealing with the urban heat island involve modifying the urban surface through vegetation and/or altering surface albedo. The former can provide an evaporating surface that cools and humidifies the air close to the ground. The latter can be used to reduce the amount of solar energy absorbed and lower surface and air temperatures. Each can be conceived as either an adaptation or mitigation measure. Buildings (and especially the roofs of city buildings) are key places where these strategies are being implemented. If the climate 'load' on a building can be reduced, then less energy is used (mitigation). If the outdoor climate is made more comfortable then this space can be used to combat thermal stresses (adaptation). However, seen in isolation from the climate background or from the urban micro-scale context, these interventions might achieve very little. For example, what is the comparative advantage of increasing the albedo of roofs versus installing photovoltaic cells (which have a low albedo)? And, what is the net effect on the heat island within the urban canopy by changing the albdeo of the roof surface?

In considering the opportunities for urban design based on the global climate change imperative, strategies must be considered in conjunction with the scales of the urban climate effect and the roles of urban form and function. An understanding of the urban effect and of indoor/outdoor perspectives is essential if such policies are to be effective.

REFERENCES

Atkinson W (1912) The Orientation of Buildings or Planning for Sunlight. John Wiley & Sons, New York).

Clancy L, Goodman P, Sinclair H and Dockery DW (2002) Effect of air---pollution control on death rates in Dublin, Ireland: an intervention study. Lancet 360, 1210– 2014.

DePaul FT and Sheih CM (1985). A tracer study of dispersion in an urban street canyon. Atmospheric Environment 19, 555–559.

Knowles RL (2003) The solar envelope: its meaning for energy and buildings. Energy and Buildings 35, 15–25.

Kwartler M. and Masters R. (1984) Daylight as a zoning device for midtown. Energy and Buildings 6, 173-189.

Lowry WP (1977) Empirical estimation of urban effects on climate: A problem analysis. Journal of Applied Meteorology 16, 129-135

Matus V. (1988) Design for northern climates: cold---climate planning and environmental design. Van Nostrand Reinhold.

Mills G. (2007) Cities as agents of global change. International Journal of Climatology, 27, 1849---1857.

Oke TR (2006) Initial guidance to obtain representative meteorological observations at urban sites. WMO/TD---No. 1250.

Birmingham Urban Climate Change with Neighbourhood Estimates of Environmental Risk. A Knowledge Transfer Partnership.

Richard Bassett

Introduction

The BUCCANEER (Birmingham Urban Climate Change with Neighbourhood Estimates of Environmental Risk) project is an exciting two year knowledge transfer initiative involving Birmingham City Council and the University of Birmingham. This Knowledge Transfer Project (KTP) is helping to provide the necessary evidence to ensure the effective delivery of the Council's long term vision that the City will be the UK's first sustainable global city with a low-carbon energy infrastructure and well prepared for the impact of climate change.

Birmingham, UK is a large metropolitan city located in the Midlands with a population in excess of one million inhabitants. A rise in mean annual temperature from 9.4°C (1960 - 1990) to 10°C (1991 - 2007) has already indicated that Birmingham is likely to be impacted by the effects of climate change (LCLIP,2007). The UKCP09 expect this increase to continue with estimates that the 2080 summer mean daily maximum temperatures rising by up to 6.6°C under a high emissions scenario in Birmingham.

However, absent to these climate projections is the complex morphology of Birmingham which creates a warming effect when compared to surrounding rural areas. This effect is strongest several hours after sunset (Oke, 1987). Termed the urban heat island (UHI), past studies have found the exact nature to be related to city size, moisture availability, land-use, anthropogenic emissions, building materials and geometry.

Research into the exact nature of Birmingham's UHI has been limited when compared to the extensive UHI research on other UK cities. Unwin (1980) identified that city centre nocturnal minimum temperatures could be in excess of 5°C warmer under anti-cyclonic conditions. However Unwin's (1980) study was not truly representative of city centre conditions, with the site located in suburban Edgbaston. Johnson (1985) furthered this research by conducting transects through Birmingham with the UHI found to be up to 4.5°C during clear, calm conditions. More recently surface UHI investigations from MODIS satellite images found night time surface UHI to be typically around 5°C and up to 7°C under extremely stable heatwave conditions (Tomlinson et al. 2010).

The UHI effect can lead to heat stress and air pollution problems which are a major health concern. In particular heatwaves have been shown to exacerbate cardiovascular diseases, cerebrovascular diseases, respiratory diseases and heat stroke. The estimated increase in overall mortality during heatwaves is reported to be between 7.6% and 33.6% with the significant majority of people affected being aged 75 and over (Health Effects of Climate Change in the West Midlands, 2010).

The 2003 European heat wave was one of the hottest summers on record in Europe. It led to a health crises in several countries and combined with a drought to create a crop shortfall in Southern Europe. More than 40,000 Europeans died as a result, including 2,045 excess deaths in

England and Wales (UK Office for National Statistics) where temperatures reached 38°C. Climate projections show that there could be an average of 3 heatwaves during July and 2 during August by 2080, leading to an increase in deaths, particularly for the elderly and vulnerable. A heatwave experienced in 2020 may lead to 53% more deaths by the 2020s than during the 2003 heatwave (Health Effects of Climate Change in the West Midlands, 2010). The problem lies that unlike any other significant weather event, heat is not treated as an atmospheric hazard.

High temperatures may have a direct impact on road surfaces, railway networks, air conditioning and machinery, as well as creating uncomfortable conditions in houses, factories, offices and public areas. High temperatures are often associated with forest fires, low water flows and a reduction in water quality in ponds and rivers. During these periods sudden rainfall can flush heavy metals and sooty deposits from roads and sewage from misconnected drains into streams and rivers.

Whilst city morphologies have been extensively researched and found to cause increased night time temperatures in urban areas, UKCP09 assume that Birmingham has an agricultural landscape. These projections therefore underestimate the temperature fluctuations caused by the UHI. Thus in order to inform new planning policies it is vital that the influence of the UHI is accounted for.

Birmingham's UHI

Birmingham's UHI is not currently modelled. The inclusions of Birmingham's urban areas in a land surface model should show the intensification of temperatures within the city centre.

In the present study, the JULES (Joint UK Land Environment Simulator) model has been setup and run for Birmingham and surrounding areas. The model is run using satellite derived land use data and Meteorological data from Coleshill, a rural weather station outside of the urban boundaries. The JULES model performance has been evaluated against air temperature measurements at two UK Met Office standard sites, Edgbaston (urban) and Winterbourne (rural).

Averaged annually over 2010, the UHI for Birmingham was found to be 0.37°C. Split diurnally, the night time UHI was found on average to be 0.89°C. A slight urban cool island was shown to develop during the day. The maximum UHI intensity modelled over 2010 was found to be 5.24°C.These modelled temperature patterns were found to be consistent with previous research findings for Birmingham (Unwin (1980), Johnson (1985)) and correlate strongly with observed temperature data at Edgbaston and Winterbourne weather stations.

The temperatures predicted by the JULES model show a strong correlation with observations over a 12 month simulation (2010) for Birmingham. The model predicts well the diurnal UHI intensity when hourly averages over a year are taken (Figure 1). On an hourly basis some variability was found with a root mean square error (RMSE) of approximately +/- 1°C. The model evaluation is also being complemented by a further UHI project

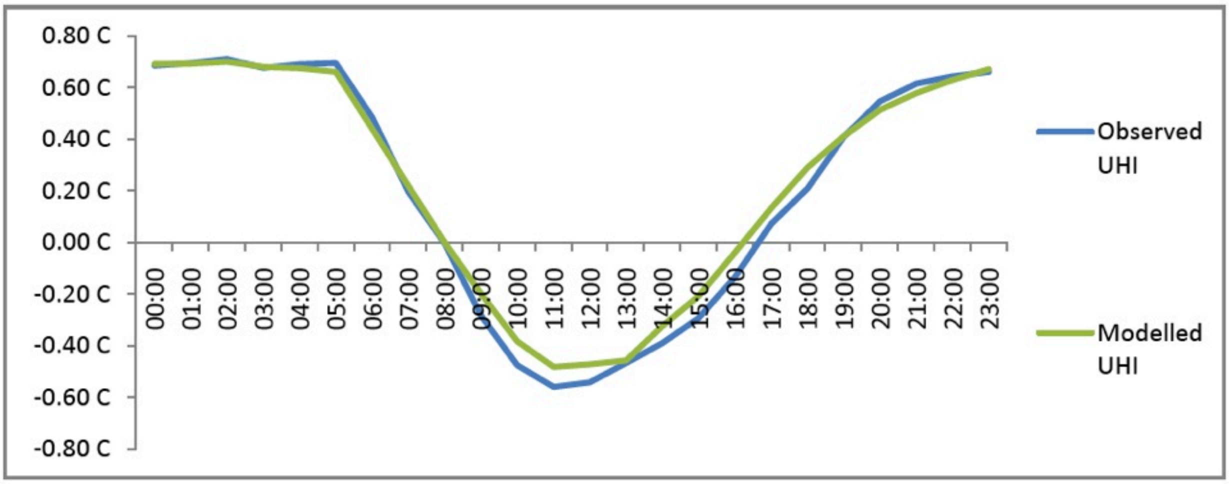

Figure 1: Observed and Modelled UHI intensities averaged over a 12 month simulation (2010) between Edgbaston (urban) and Winterbourne (rural) weather stations.

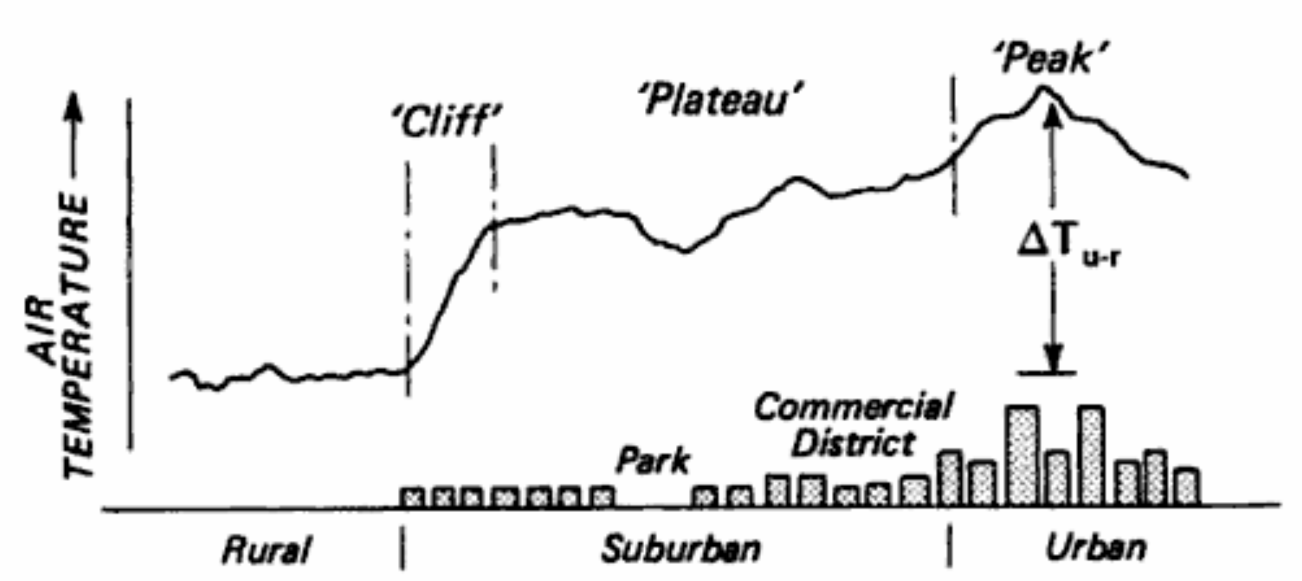

Figure 2: UHI Transect showing the typical temperature profile across a city (Oke, 1987)

using tiny-tag data logger temperature measurements around Birmingham and proposals to set up further sensors in the city centre. Annual mean temperature differences as little as 0.05°C were found between the observed and predicted sites. This indicated the models suitability for use in the BUCCANEER project.

In general the model was found to under predict the night time UHI intensity and over predict the day time cool island effect, particularly when modelling a heatwave scenario. When considering the sources of uncertainty the model does perform well. For example, the point locations of the observation may have an entirely different land use to the average land use of the 500m grid cell around it. At this scale small scale meteorological effects such as shading, frost hollows could alter the temperatures enough to explain the slight differences between observed and modelled results. Further to this, limitations in data driving the model, such as the long wave radiation input required for the model being estimated as a function of the atmosphere could lead to deviations between observed and predicted values.

Currently the validation of the model is continuing as new data becomes available. Several new projects starting at the University will put Birmingham at the forefront of urban climate research. An additional project (HiTemp) which aims to establish a high-density urban climate network in Birmingham will provide abundant data for further validation. The data validation will also be complimented by a new met-office standard weather station, located in the city centre which is expected to be fully operational from July 2011.

Several key urban heat island features became apparent when the model simulations for Birmingham were run (Figure 3). For example a marked temperature gradient, the so called urban temperature cliff (Figure 2) was found when moving from the Edgbaston area to the city centre. Under a heatwave condition the model was showing a temperature gradient in excess of 1°C per kilometre. Spatially the pattern of the UHI was found to resemble the satellite derived urban heat island for Birmingham (Figure 3). Direct comparisons have not yet been established due to the characteristic difference between the surface and the near surface urban heat islands.

Knowledge Transfer and Resulting Action

One of the main focuses of this project is the sharing of information between the University of Birmingham and Birmingham City Council. Ensuring that the science and findings of the research can be applied directly to inform policy decisions has been a key deliverable throughout the project.

The task of transferring research findings into a simple, easy to understand format that is both transferable and widely available to project

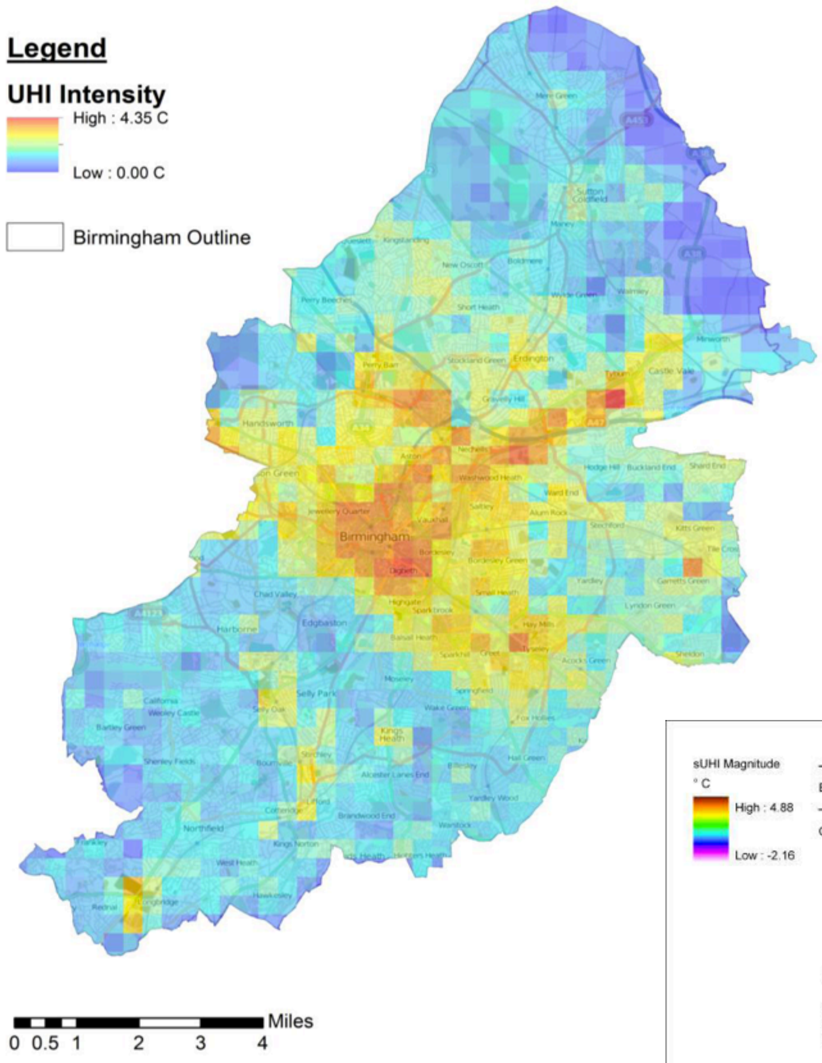

Figure 3: Birmingham's modelled UHI during the 2006 heatwave (18th July, 01:00)

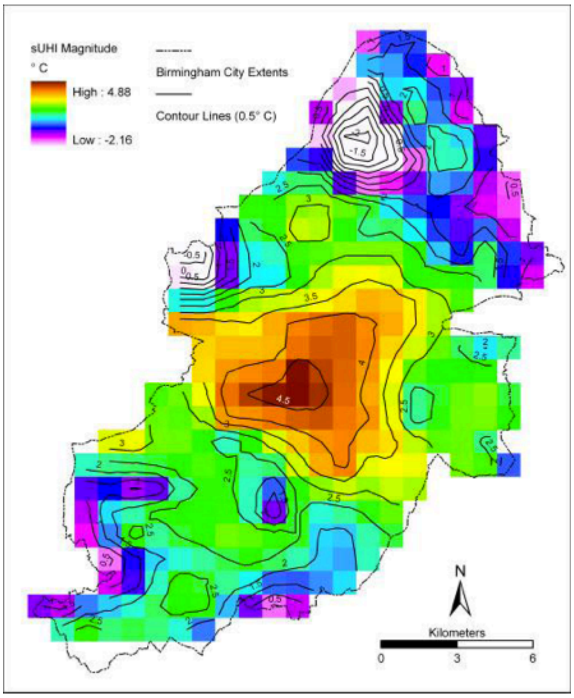

Figure 4: Satellite derived surface UHI (Tomlinson et al. 2010)

partners is an on-going challenge. It is ideally thought that the BUCCANEER project can be a means in which different service areas from within Birmingham City Council and the University can communicate, interact and share data. In order for this to be achieved, a user-friendly web interface has been created - The BUCCANEER Planning Tool (Figure 5). The tool aims to:

- Visually display information in a user friendly format.
- Address the impact of the combined effects of the urban heat island and climate change on different temporal and spatial scales across the city.
- Highlight vulnerable social and environmental areas through risk mapping layers.
- Allow users from other projects to upload and compare information layers.

The tool will allow the UHI heat layers to be overlaid, using GIS (Geographical Information Systems) with vulnerability layers developed from a risk mapping project at the University of Birmingham. These layers use social, economic and environmental data to create risk maps with a particular focus on heath and demographic vulnerabilities. For example proportion of people with ill health in high density housing that will be exposed to excess heat.

By overlaying these layers the BUCCANEER project will provide a greater understanding of the interlinked social, economic and environmental risks presented by extreme weather events and future climate change. The project will equip service areas such as planners and health protection agencies with the necessary tools needed to adapt to the impacts of climate change in Birmingham.

Already the tool has been incorporated into Birmingham's planning process with inclusion in the Emerging Core Strategy (see section 5.40). Birmingham's Climate Change Adaptation Action Plan which is currently being produced also highlights the BUCCANEER as a primary planning tool. The Action Plan will highlight the risks and vulnerabilities Birmingham faces as a result of climate change and the core actions both underway and future actions that need to be developed. This will be a key document outlining the strategic direction both BCC and its partners must take to ensure Birmingham is prepared for a changing climate. The report pulls together the various studies undertaken (including the BUCCANEER) to provide a holistic assessment of the best way forward to benefit from the economic, social and environmental benefits of adapting to climate change. The action plan will assess the actions necessary in different sectors as well as at a community level. These will be further identified in the context of both short and long term measures. Crucially this action plan will provide the framework for developing individual neighbourhood action plans in the following year. The BUCCANEER Planning Tool (Figure 5) will thus become:

- A valuable aid for planners.
- An instrument to help inform and develop strategic policies.

Conclusion and Future directions of the Project

The next stage of the project is to drive the JULES model on statistically plausible future hourly weather sets from the UKCP09 weather generator. The intention is to identify any spatial heat distribution changes in Birmingham and the difference in number of heat related events compared with not incorporating the UHI into future climate predictions.

The model will also be run to assess the effectiveness of climate change adaptation strategies, for example the cooling effect of adding an extra 10% green infrastructure in the city centre. These future climate and hypothetical

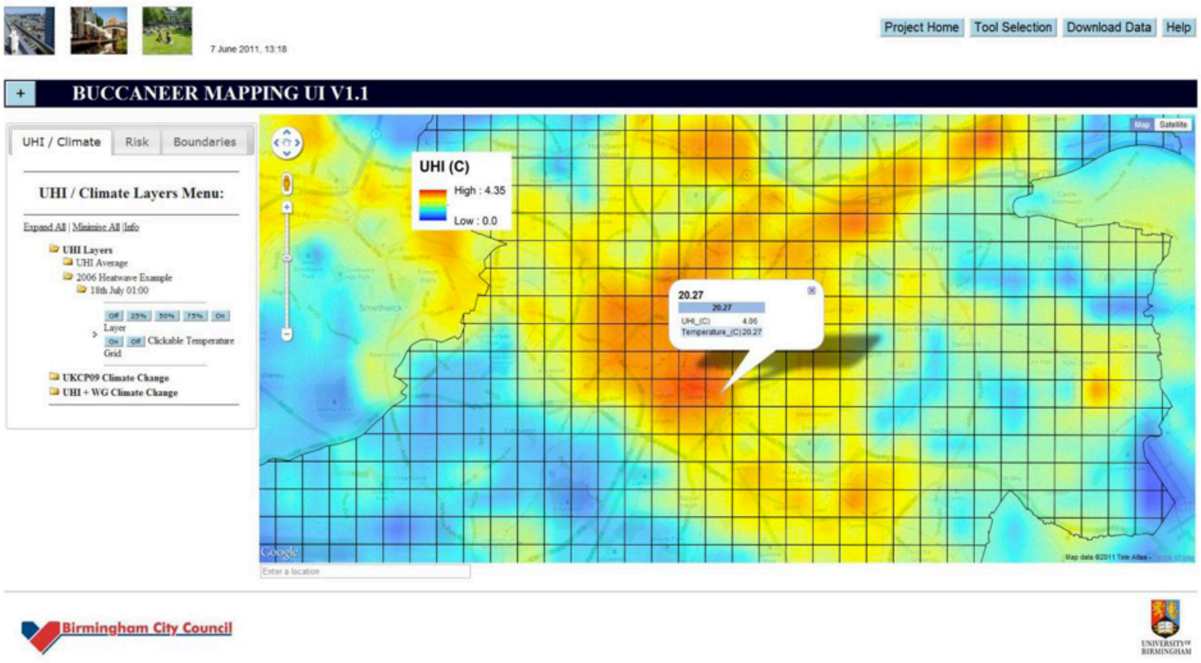

Figure 5: Example of the BUCCANEER Tool User Interface displaying the UHI for Birmingham under a heatwave example

adaptation scenarios will then be fed into the BUCCANEER tool as layer sets. The tool will also include “what if?” scenarios, i.e. the user will be able to select their location in Birmingham and then modify the land use and model properties to mimic adaptation strategies to assess their strengths and weakness' in adapting to climate change.

REFERENCES

Birmingham City Council, Emerging Core Strategy 2010: http://www.birmingham.gov.uk/cs/Satellite?%26ssbinary=true&blobcol=urldata&blobheader=application%2Fpdf&blobheadername1=Content-Disposition&blobkey=id&blobtable=MungoBlobs&blobwhere=1223448040897&blobheadervalue1=attachment%3B+filename%3D1921010The+Birming

Johnson D.B., 1985. Urban Modification of Diurnal Temperature Cycles in Birmingham UK. Journal of Climatology 5: 221-225.

Joint UK Land Environment Simulator: http://www.jchmr.org/jules/

Kotecha R., Thornes J., Chapman L., 2008. Birmingham’s Local Climate Impacts Profile (LCLIP).

May E., Bairdi L., Kara E., Raichand S., Eshareture C., Fisher P., Kemm J., Beckett S., Crompton T., Reeves C., 2010. Health Effects of Climate Changes in the West Midlands: Technical Report.

Oke T.R., 1987. Boundary layer Climates, 2nd Ed. Methuen, London.

Tomlinson C.J., Chapman L., Thornes J.E., Baker C.J., 2010. Derivation of Birmingham's summer surface urban heat island from MODIS satellite images. International Journal of Climatology

UKCP09: UK Climate Impacts Programme: http://ukcp09.defra.gov.uk/

UK Office for National Statistics: http://www.statistics.gov.uk/hub/index.html

Unwin D.J., 1980. The Synoptic Climatology of Birmingham’s Urban Heat Island, 1965-74. Weather 35: 43-50.

Exploring The Urban Heat Island Intensity Of Dutch Cities

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1. Introduction

In contrast to many countries in the world, where urban meteorology has been studied for more than three decades (Arnfield, 2003), urban meteorology was not an issue in the Netherlands until recently. The Urban Heat Island (UHI) effect was considered to be relatively unimportant for Dutch weather conditions because of the mild climate and mitigating influence of the North Sea. This view changed after the heat waves in 2003 and 2006 that caused an excess mortality between 1000 and 2200 in the Netherlands (Haines et al., 2006). These numbers are relatively high as compared to those reported for other European countries (EEA, 2008). Particularly in the cities excess mortality rates were high which made many people realize that also Dutch cities are impacted. In addition, climate change projections indicate that also in the Netherlands hot days are likely to become more frequent in the next decades (Fischer and Schär, 2010; van den Hurk et al., 2006).

Urbanization, particularly in the western and central part of the country, will continue in the next decades. Future projections show a large expansion of the urban landscape of up to 20% (Nijs et al. 2002; MNP, 2002). Hence, there is now a sense of urgency to implement adaptation measures in order to cope with future climate threats on the liveability in cities. However, knowledge regarding the UHI intensity of Dutch cities has been completely lacking. With the exception of a study carried out in 1969-1970 on the UHI effect of Utrecht (Conrads, 1975) and a recent study to assess the long term validity of KNMI (Royal Netherlands Meteorological Institute) temperature time series (Brandsma et al. 2003), no systematic meteorological data records are available. This hinders the design of suitable adaptation and heat mitigating strategies.

In the present study, the magnitude of the current UHI-intensity in urban areas in the Netherlands has been explored. The underlying question is whether thermal comfort already is or will become a critical issue in the next decades. The assessment is based on a literature review, preliminary results from recent meteorological observations in the urban canopy in Rotterdam and Arnhem, as well as on datasets provided by hobby meteorologists.

2. Urban Heat Island Intensity

Mobile traverse measurements in the city of Rotterdam and Arnhem The UHI intensity of Rotterdam was mapped on 6 August 2009, a golden day with a maximum and minimum air temperature of 29.7 and 16°C respectively (measured at WMO station near the airport of Rotterdam-The Hague). The measurements were performed using two cargo bicycles as a mobile monitoring platform, equipped specifically for urban meteorological measurements (Heusinkveld et al. 2010).

Relatively small temperature differences were measured during the early afternoon (14- 16 CET). Air temperatures in the densely built areas were 1-2 K higher than the temperatures measured at Rotterdam airport, whereas lower air temperatures (1–2 K) were measured in the city park along the route (Fig.1 left panel, arrow). In contrast, large differences were measured during the late evening (22-24 CET, Fig. 1 right panel). The air temperature of the city centre was about 5 K higher than the one measured near the Rotterdam-The Hague airport, and the difference between the city and the surrounding countryside amounted to more than 7 K during nocturnal hours. These preliminary results clearly demonstrate the existence of a considerable UHI in the city centre and other densely built areas in Rotterdam.

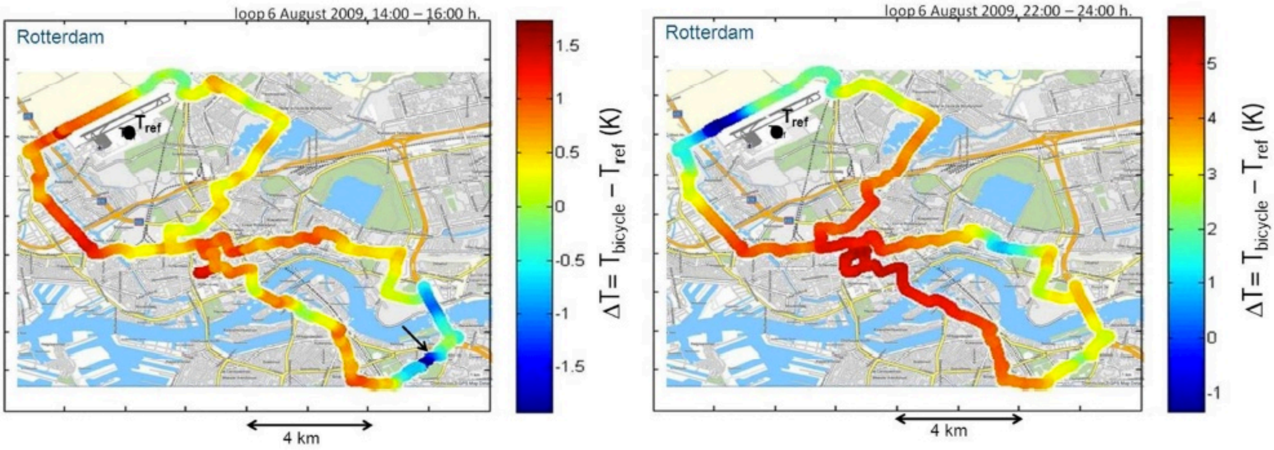

Figure 1: North and south loop of the mobile traverse measurements in Rotterdam on 6 August 2009. Air temperature differences between cargo bike and reference station (WMO station Rotterdam-The Hague airport) at 14-16 (left panel) and 22-24 (right panel) CET. Note the differences in △T-scale (Heusinkveld et al., 2010).

Mobile traverse measurements have also been carried out in the city of Arnhem (146,000 inhabitants) which is located more inland. The measurements were carried out on 19 August 2009 under comparable weather conditions as those in Rotterdam. These measurements also show a substantial nocturnal UHI intensity (~7 K), despite the smaller city size.

Long-term measurements in the city of Rotterdam

Since September 2009 a small monitoring network consisting of three Automatic Weather Stations (AWS) is operational in Rotterdam (van Hove et al., 2010). The stations, labelled as Rotterdam-Centre, –East and –South, represent the densely built commercial area, the relatively green suburban living neighbourhood and the densely built up living neighbourhood respectively (see Table 1 for coordinates). These locations can be classified as 1, 2 and 3 respectively, according to the Urban Climate Zone (UCZ) classification of Oke (2006). The monitoring results of these stations are compared with those of a reference AWS located in the rural area, north of Rotterdam (51°58’55.17”N, 4°25’45.31”O).

Figure 2 shows the variation in UHI intensity for the three monitoring locations in Rotterdam determined for the period September 2009 to March 2011. Plotted are values for the maximum UHI intensity during a 24-hour period (UHImax in K) which is usually reached after sunset, during the evening hours. In addition, Table 1 shows the median, 95 and 98 percentile values and the maximum UHImax values determined for the summer and winter period for the three locations.

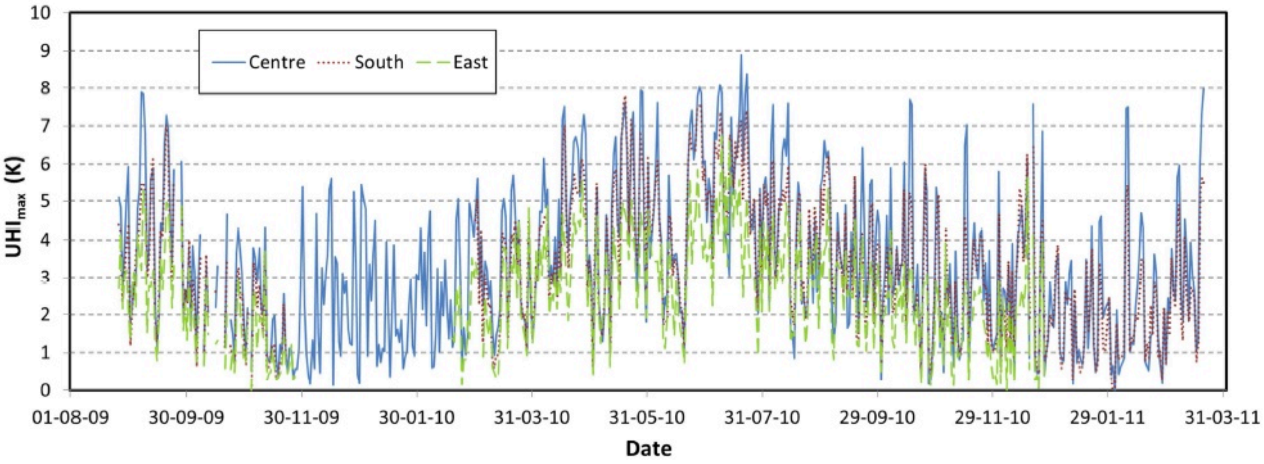

Figure 2: Maximum UHI intensity during a 24-hour period (UHImax in K) for the monitoring locations Centre, East and South in Rotterdam for the period September 2009 to March 2011.

The summer months have the highest UHImax values, with e.g. 95 percentile values of 7.8 K in the city centre, whereas lower values are found in the winter months. However, also on winter days with favourable weather conditions (i.e. clear sky, low wind speed), UHImax may be substantial, reaching 5 K or more. The densely built location Centre shows the highest UHImax, followed by the locations South and East, respectively.

Meteorological observations from hobby meteorologists

In order to obtain a more nationwide coverage, the meteorological observations provided by hobby meteorologists were analysed. Data from 19 urban sites (Fig. 3) have been collected, including air temperature and humidity, wind speed, and for some stations also incoming solar radiation (Steeneveld et al. 2011). In order to detect the UHI, each urban station has been coupled to meteorological observations at the closest KNMI rural station. The UHI has been determined as the city air temperature minus the rural air temperature at screen level, and has been recorded based on hourly data.

Most urban weather stations are located outside the city centres. The source area of 15 out of 19 stations can be classified as UCZ [3]3 (Oke, 2006). Table 3 shows the median values and the 95 percentile UHImax values. Large values are obtained for Rotterdam which is in agreement with our mobile and in situ measurement results. However, it should be noted that also for a small, more inland located settlement such as Losser, relatively large median and 95P UHImax values are obtained. Conversely, relatively small UHI intensities are found for Groningen, Assen,

Table 1. Median, 95 percentile (95P), 98 percentile (98P) and maximum (MAX) values for the hourly mean UHImax values for the 2010 summer period (1 April – 30 September 2010) and winter period of 2009/2010 and 2010/2011 respectively, for the monitoring locations Rotterdam City centre, South and East. N is the number of values in the respective periods.

		Centre	**South**	**East**
	coordinates	51°55’24.18”N 4°28’10.35”O	51°55’31.41”N 4°32’54.13”O	51°53’16.59”N 4°29’17.83”O
	UCZ[1]	1	2	3
Summer 2010				
	N	183	183	183
	Median	4.6	4.4	3.4
	95P	7.8	7.0	5.3
	98P	8.0	7.5	5.7
	Max	8.9	7.8	6.7
Winter 2009/2010				
	N	180	81	96
	Median	2.2	2.3	1.4
	95P	5.1	4.5	3.8
	98P	5.4	4.5	4.5
	Max	5.7	5.0	4.8
Winter 2010/2011				
	N	171	171	87
	Median	2.3	2.2	2.0
	95P	6.7	5.2	3.8
	98P	7.5	5.6	4.2
	Max	8.0	6.4	5.7

[1]: Urban Climate Zone classification of Oke (2006)

Figure 3: A map of the Netherlands showing where observations from hobby meteorologists are available (·). Locations of the KNMI rural stations are also shown (◊). Numbers refer to Table 3.

Damwoude and Leeuwarden. These cities are located in the less densely populated northern part of the country and relatively close to the sea.

Comparison between Dutch cities and other European cities

In Figure 4, the UHImax values reported in the literature for European cities and the available results in the present study for Dutch cities have been plotted versus the logarithmic value of the number of inhabitants (log(P)). It shows that the UHImax values assessed for Dutch cities are of the same order of magnitude as those found for other European cities. However, no significant relationship between UHImax and log(P) could be assessed suggesting that not only large settlements but also smaller ones may show significant UHI effects.

Table 3. Median and 95 percentile (95P) values for the maximum UHI intensity (UHImax) in a diurnal cycle.

	City	**Number of inhabitants (x1000)**	**Start data**	**End data**	**UCZ**[1]	**UHI$_{max}$**	
						median	**95P**
1	Apeldoorn	160	01/2008	06/2009	5	2.9	6.2
2	Assen	65	01/2007	03/2009	3	1.8	4.0
3	Damwoude	5.5	01/2005	04/2009	5-7	1.3	3.2
4	Delft	97	01/2007	03/2009	2-3	1.7	4.8
5	Doornenburg	2.7	06/2007	06/2009	5	2.6	5.7
6	Groningen	198	01/1999	03/2009	3	1.5	3.1
7	Haarlem	149	12/2005	02/2008	3	2.5	5.7
8	Heemskerk	39	01/2005	12/2008	3	2.8	5.9
9	Heerhugowaard	50	01/2005	04/2009	3-5	2.4	6.2
10	Houten	47	07/2006	04/2009	3	1.2	3.0
11	IJsselmuiden	12	07/2005	07/2009	3	3.1	6.8
12	Leeuwarden	94	01/2007	03/2009	3-5	1.1	3.0
13	Leiden	117	03/2004	03/2009	3	3.2	5.6
14	Losser	23	01/2003	12/2008	3-5	2.9	6.8
15	Purmerend	79	01/2008	03/2009	3	2.5	4.6
16	Rotterdam	588	12/2007	03/2009	2-3	3.4	7.6
17	The Hague	483	07/2007	04/2009	3-5	2.2	5.3
18	Voorburg	40	01/2006	12/2008	2	2.4	5.6
19	Wageningen	35	01/2008	07/2010	3-5	2.4	5.6

[1]: Urban Climate Zone classification of Oke (2006)

3. Thermal comfort

To get an impression about the current impact on thermal comfort, thermal indices (PET and WBGT) were calculated from the gathered meteorological data. Thermal comfort in Rotterdam All meteorological variables relevant for human microclimate (i.e. temperature, humidity, wind speed, radiation) were measured with the mobile monitoring platforms and monitoring network in Rotterdam. In this way, we were able to calculate the Physiological Equivalent Temperature (PET) which is a measure for thermal comfort based on the human heat balance (Höppe, 1999). The calculations have been carried out with the RayMan model using the default settings (Matzarakis et al., 2007).

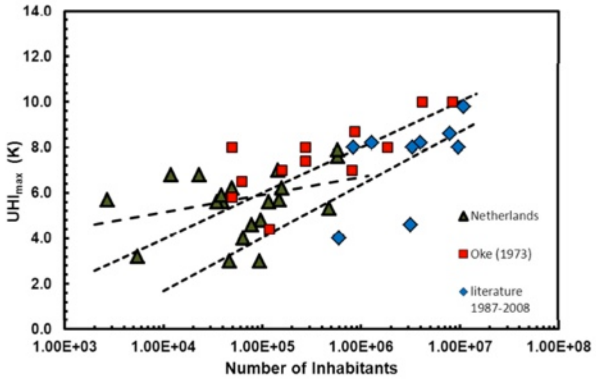

Figure 4: UHImax (95 percentile values, in K) for Dutch cities compared with UHImax values reported for European cities. Dashed lines are the linear regression lines calculated for the results of Oke (1973), for more recent results published in the scientific literature (1987-2006), and for the Dutch cities (r2 is 0.57, 0.32 and 0.07, respectively)

Fig. 5 shows the results for the mobile traverse measurements. Large spatial differences in PET for the hot afternoon are found, varying from 45-50 °C (i.e. strong to extreme heat stress) to 30-35°C (i.e. moderate heat stress). The urban area south of the river, some parts of the city centre, and the industrial area at the north-west show the highest PET values. However, high PET values are also found for the rural area north of Rotterdam.

After sunset, the city centre and adjacent neighbourhoods show the highest values, ranging from 23 to 27 °C. These values are exceeding the threshold value for light heat stress (Fig. 5 right panel). Neighbourhoods with low buildings and extensive green spaces appear to have the lowest PET values during both daytime and evening hours.

From the results of the monitoring network, hourly-average PET values were calculated for the summer season of 2010 (April – September) and related to the comfort classes given by Matzarakis et al. (1999). The measured globe temperature was used as an approximation of the mean radiant temperature. Figure 6 shows the frequency distributions for the resulting comfort classes. The frequencies are expressed against the total number of hours in each month. So, we did not distinguish between day and night.

The number of hours that can be classified as “heat stress hours” was larger at the urban sites than at the reference rural site. June and July were

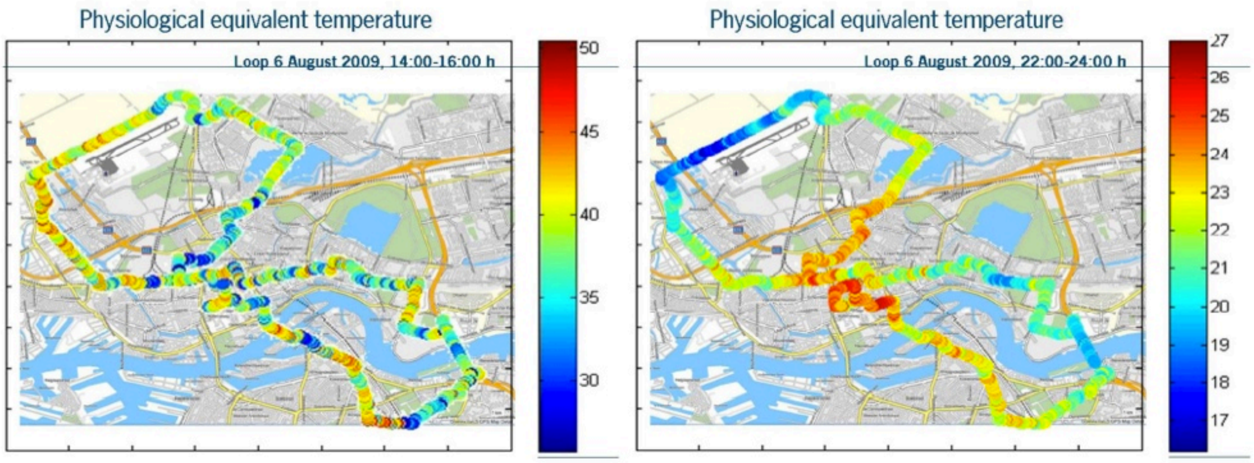

Figure 5: Physiologically Equivalent Temperatures at 14-16 (left panel) and 22-24 CET (right panel) calculated from the results of the mobile traverse measurements on 6 August 2009. Note the differences in PET scales (Heusinkveld et al., 2010).

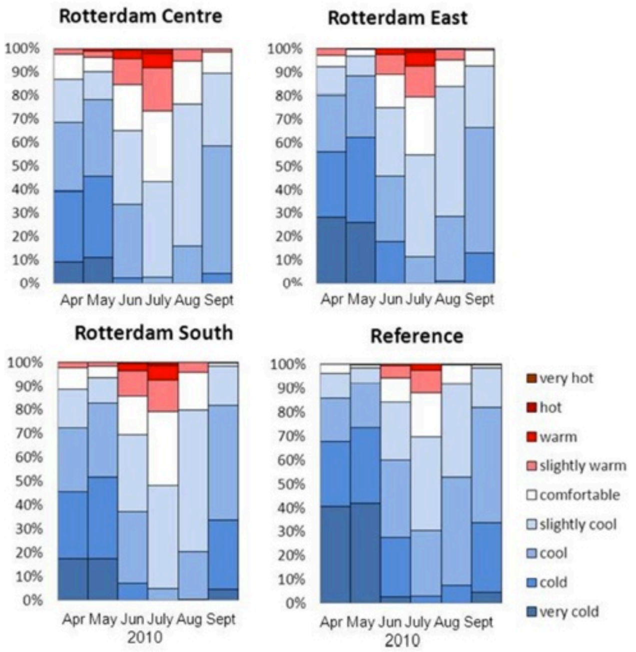

Figure 6: Frequency distribution for the different thermal comfort classes for the summer season of 2010 (15 April – 30 September 2010)

months with the highest average air temperatures in 2010. In June, the average number of hours with heat stress (moderate to strong) for all urban stations was ~22, in July this was ~60 hours: i.e. ~3% and ~8% of the total number of hours for each month (720 and 744 respectively). At the reference rural site this was ~0.6% (June) and ~2.7% (July) or ~4 and ~20 hours, respectively. Considering that the highest PET values usually occur between 11:00 h and 19:00 h (LT), this would imply that in June and July there were ~3 and ~8 days, respectively, with moderate to strong heat stress.

Thermal comfort in other Dutch cities

Because PET could not be calculated from the data provided by the hobby meteorologists we made estimations of the Wet Bulb Globe Temperature (WBGT), using an approximation based on air temperature and water vapour pressure (BOM, 2008). General threshold values for WBGT are not available, but largely depend on a person's activities or work load. For the general public, a WBGT of 27.7 °C represents a threshold value above which most people start feeling discomfort. Physical training is not advised for WBGT > 29.4 °C and WBGT > 31 °C usually results in cancellation of sport events (Sobane, 2008). The median values of all cities are far below the threshold value of 27.7 °C. Only the 95 percentile value for Rotterdam exceeds this threshold value and its 98 percentile value is even above the upper limit for event cancellation. For another six cities, the 98 percentile WBGT value was found to exceed the threshold value for heat stress onset. This would imply that these cities experience heat stress for ~7 days a year and for Rotterdam this would be ~18 days a year.

4. Discussion and conclusions

The results from the recent meteorological observations in Rotterdam and Arnhem are largely consistent with the results obtained from the hobby meteorologists data. All point to the existence of a considerable UHImax in densely built areas in the Netherlands under favourable meteorological conditions, i.e. under calm and clear (cloudless) conditions, with 95 percentile values ranging from 3 to 8 K. The UHImax values determined for Dutch towns and cities appear to be of the same order of magnitude as those reported for other European cities.

However, no clear relationship between city size (here defined as the logarithmic value of the number of inhabitants) and UHI intensity was found suggesting that not only large settlements but also smaller ones may show significant UHI effects.

The preliminary results for PET in Rotterdam show that the number of hours classified as "heat stress hours", is higher in the urban area than in the surrounding rural area during warm and hot days.

However, large spatial differences exists and micro climate at a specific urban site may be even more comfortable than that in the surrounding rural area during a day with high solar radiation, e.g. due to the presence of trees or shadowing effects of buildings.

According to the WBGT results estimated from the hobby meteorologist data, Rotterdam experiences more heat stress days than the other studied cities. The 98 percentile WBGT values of one third of the studied cities has been found to exceed the threshold value for heat stress suggesting that current thermal comfort may already be critical in many urban areas in the

Table 4: Median, 95 and 98 percentile values for the Wet Bulb Globe Temperature (WBGT) as an indicator of heat stress. Bold: exceedance of the threshold WBGT values of 27.7 °C.

				WBGT (°C)		
	City	**# inhabitants (x1000)**	**UCZ[1]**	**median**	**95P**	**98P**
1	Apeldoorn	136	5	14.5	24.5	25.1
2	Assen	65	3	15.8	25.0	26.4
3	Damwoude	5.5	5-7	16.0	25.2	26.9
4	Delft	97	2-3	16.6	25.2	27.5
5	Doornenburg	2.7	5	10.5	14.3	15.2
6	Groningen	198	3	16.2	26.4	**28.7**
7	Haarlem	149	3	-	-	-
8	Heemskerk	39	3	13.7	21.3	24.1
9	Heerhugowaard	50	3-5	16.6	25.6	**27.8**
10	Houten	47	3	12.8	20.8	23.0
11	Ijsselmuiden	12	3	16.6	25.4	**27.8**
12	Leeuwarden	94	3-5	15.8	24.1	26.0
13	Leiden	117	3	18.5	26.6	**28.2**
14	Losser	23	3-5	16.3	26.2	**28.0**
15	Purmerend	79	3	14.0	23.2	24.8
16	Rotterdam	588	2-3	15.1	**29.7**	**32.3**
17	The Hague	483	3-5	16.0	25.3	26.9
18	Voorburg	40	2	17.5	25.8	**28.5**
19	Wageningen	35	3-5	17.6	25.6	27.6

[1]: Urban Climate Zone classification of Oke (2006)

Netherlands. However, both PET and WBGT have their limitations. Whether or not citizens feel comfortable with the urban micro climate they encounter, depend on a complex interaction between physical, physiological, behavioral, and psychological factors. People may have a long-term microclimate perception which differ from microclimate reality (Lenzholzer, 2009). These long-term perceptions may dominate behavioral responses and the acceptance or avoidance of public spaces. Also, people may accustom to a future climate with higher air temperatures (McMichael et al., 2006). These examples illustrate that it is not always easy to relate thermal comfort indices to actual experienced comfort or heat stress, or even more, to make predictions. Nevertheless, it can be concluded from the present study that considering future developments in climate and urbanization, thermal comfort will likely become critical in many urban areas in the Netherlands.

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REFERENCES

Arnfield A. J., 2003. Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island. Int. J. Clim., 23; 1–26.

Brandsma, T., G.P. Können, and H.R.A. Wessels, 2003. Empirical estimation of the effect of urban heat advection on the temperature series of De Bilt (The Netherlands). Int. J. Clim., 23; 829-845.

Conrads, L.A., 1975. Observations of meteorological urban effects. The heat island of Utrecht. PhD thesis University Utrecht, 84 pp.

EEA , 2008. Impacts of Europe's changing climate -2008 indicator-based assessment. Joint EEA-JRC-WHO report. ISSN 1725-9177, 246 pp.

Fischer, E.M. and C. Schär, 2010. Consistent geographical patterns of changes in high-impact European heat waves. Nature Geoscience, Published online: 16 May 2010, DOI: 10.1038/NGEO866, 1 - 6.

Haines, A., R.S. Kovats, D. Campbell-Lendrum and C. Corvalan, 2006. Climate change and human health: impacts, vulnerability, and public health. Lancet, 367, 2101-2109.

Heusinkveld, B.G., L.W.A. van Hove, C.M.J. Jacobs, G.J. Steeneveld, J.A. Elbers, E.J. Moors, and A.A.M. Holtslag, 2010. Use of a mobile platform for assessing urban heat stress in Rotterdam. Proceedings of the 7the Conference on Biometeorology. Albert-Ludwigs-University of Freiburg, Germany, 12-14 April 2010. 433-438. http://www.meteo.uni-freiburg.de/forschung/publikatione/berichte/index.html

Höppe, P., 1999. The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. Int. J. Biometeorol. 43; 71-75.

IPCC, 2007, Climate Change 2007, Impacts, Adaptation and Vulnerability, Working Group 2 contribution to the IPCC Fourth assessment report.

Lenzholzer, S., 2009. Engrained experience—a comparison of microclimate perception schemata and microclimate measurements in Dutch urban squares. Int. J. Biometeorol. Published online. DOI 10.1007/s00484-009-0262-z.

Matzarakis, A., H. Mayer and M.G. Iziomon, 1999. Applications of a universal thermal index: physiological equivalent temperature. Int J Biometeorol 43; 76–84.

Matzarakis A., F. Rutz and H. Mayer, 2007. Modelling radiation fluxes in simple and complex environments—application of the RayMan model. Int J Biometeorol 51; 323–334.

McMichael A. J., R.E. Woodruff and S. Hales, 2006. Climate change and human health: present and future risks. Lancet 367 (9513): 859–869.

MNP, 2002. Nationale Natuurverkenning 2, 2000-2030, Milieu- en Natuurplanbureau. Kluwer, Alphen aan de Rijn.

Nijs, T. de, L. Crommentuijn, H. Farjon, H. Leneman, W. Ligtvoet, W. De Niet and K. Schotten, 2002. Vier scenario's van het landgebruik in 2030. Achtergrondrapport bij de Nationale Natuurverkenning 2, RIVM rapport 408764003, RIVM, Bilthoven. 88 pp.

Oke, TR., 1973. City size and the urban heat island. Atm. Env. 7; 769–779.

Oke, T.R., 2006. Initial guidance to obtain representative meteorological observations at urban sites. Instruments and observing methods, 81. Canada. World Meteorological Organization.

Sobane, 2008. Werkomgeving en fysische agentia. http:www.sobane.be/nl/klimaat/pdf/klific14.pdf

G.J. Steeneveld, S. Koopmans, B.G. Heusinkveld, L.W.A. van Hove, A.A.M. Holtslag 2011. Quantifying urban heat island effects and human comfort for cities of variable size and urban morphology in the Netherlands. J. Geophys. Res. 116, D20129, 14pp., doi: 10.1029/2011 JDO15988.

Van Hove, B., G-J Steeneveld, C. Jacobs, H. ter Maat, B. Heusinkveld, J. Elbers, E. Moors and B. Holtslag, 2010. Modelling and observing urban climate in the Netherlands. KvR report 020/10, 48 pp.

Van Den Hurk, B., A. Klein Tank, G. Lenderink., A. Van Ulden, G.J. Van Oldenborgh, C. Katsman, H. Van den Brink, F. Keller, J. Bessembinder, G. Burgers, G. Komen, W. Hazeleger, and S. Drijfhout, 2006. KNMI Climate Change Scenarios 2006 for the Netherlands, KNMI Scientific Report WR 2006-01. KNMI, De Bilt, 82 pp.

Four Decades Of Urban Climatic Map Studies: A Review

Chao Ren, Edward Ng and Lutz Katzschner

1. Introduction

Sustainable urban planning from the urban climatic point of view has been a topical issue for city planners and policy makers. However, the application of urban climatic knowledge has a low impact on urban planning and policy decision making of urban development. Since the 1970s, people have looked for ways to assemble quickly urban climatic information for planning actions in a format that is user-friendly to planners (Chandler, 1976; Page, 1976; WHO & WMO, 1970). The concept of Urban Climatic Map (UCMap) was first developed by German researchers in the late 1970s (Matzarakis, 2005). In German it is called “Klimaatlas” that means a collection of climatic maps. UCMap is an information and evaluation tool to integrate urban climatic factors and town planning considerations by presenting climatic phenomena and problems into two-dimensional spatial maps (Baumüller et al., 1992; Scherer et al., 1999; VDI, 1997). It provides a visual and spatial information platform on planner-friendly Geographical Information System.

In this paper, firstly it briefly reviews the history of UCMap study and focuses on the relevant German and Japanese UCMap study. Secondly, it introduces the structure of UCMapping system and its basic concept and components. Thirdly, the paper shortly discusses the advantage and limitation of UCMap study. Finally, it reveals the future trend of UCMap study.

2. History of UCMap Study

Since their introduction 40 years ago, worldwide interest in urban climatic map studies has grown. Today, there are over 20 countries around the world processing their own climatic maps (Figure 1), developing urban climatic guidelines, and implementing mitigation measures for local planning practices (Ren et al., 2010). Among them, Germany and Japan are two pioneer countries in UC-Map studies based on reviewing international examples.

Figure 1: UCMap Studies around the world (in 2011)

Figure 2: German Cities conducting the UCMap studies

2.1 UCMap study in Germany

Germany has the strong focus of urban climate research on applied urban climatology (Matzarakis, 2005). Prof. K. Knoch's publication Die Landesklima-aufanhme (1963) firstly mentioned intention of climate mapping system for planning purposes (Sterten, 1982). Since the early of the 1970s, West-Germany has intensified its geo-scientific activities in presenting maps relevant to planning (Lüttig, 1972, 1978a, 1978b). Especially in Stuttgart, the Department of Urban Climate led by Prof. J. Baumüller has begun to apply the climatic information and knowledge in the real planning case. Later on, with the development of UCMap studies in Germany, more and more German cities and regions acted and generated their own UC-ReMaps together with planning recommendations, such as Kassel, Berlin, Freiburg and so on (Figure 2).

In these studies, not only climatologists contribute their effort, but also German Government plays an important role to pursue a precautious development. According to German Federal Building Code (Baugesetzbuch-BauGB), there are several environmental regulations for urban development planning. So local authorities could take the climatic knowledge and study result into account, when they make a regional or urban development.

As a milestone of UCMap study, in 1997 the Guideline for drawing up climate and air pollution maps (VDI3787 Part1) was published as a standard by the work group of Urban Climatic Map Committee of applied climatology. It aimed to offer some expert advices on the methodology of creating UC-Map from analytical and evaluative facts (Figure 3) and also define the symbols and representations used in UC-AnMap and UC-ReMap. Another important reference is Climate Booklet for Urban Development: Reference for Zoning and Planning by Office for Environmental Protection of Stuttgart City Government. Both of them are widely used as important reference.

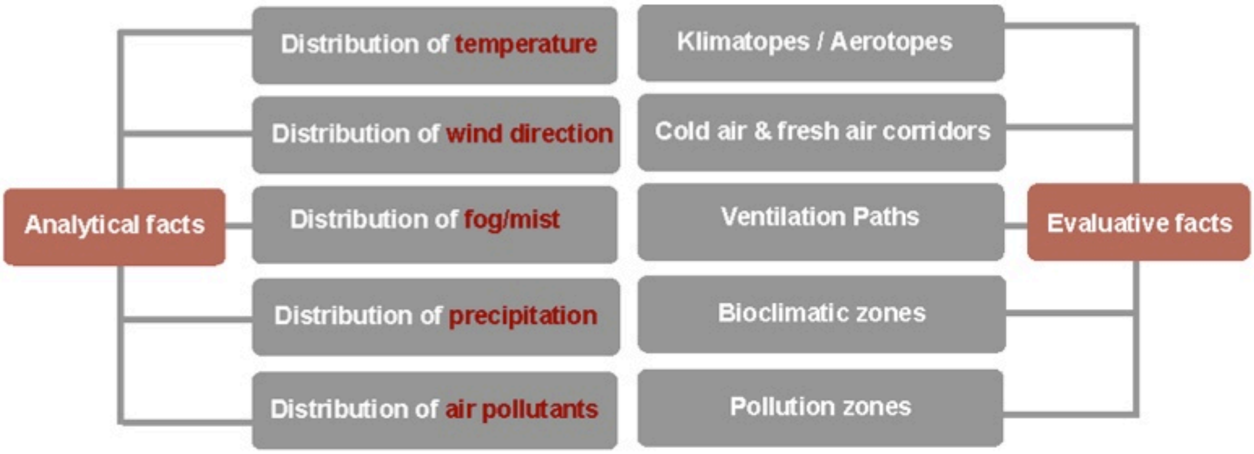

Figure 3: The analytical facts and evaluative facts recommended by VDI 3787 Part 1

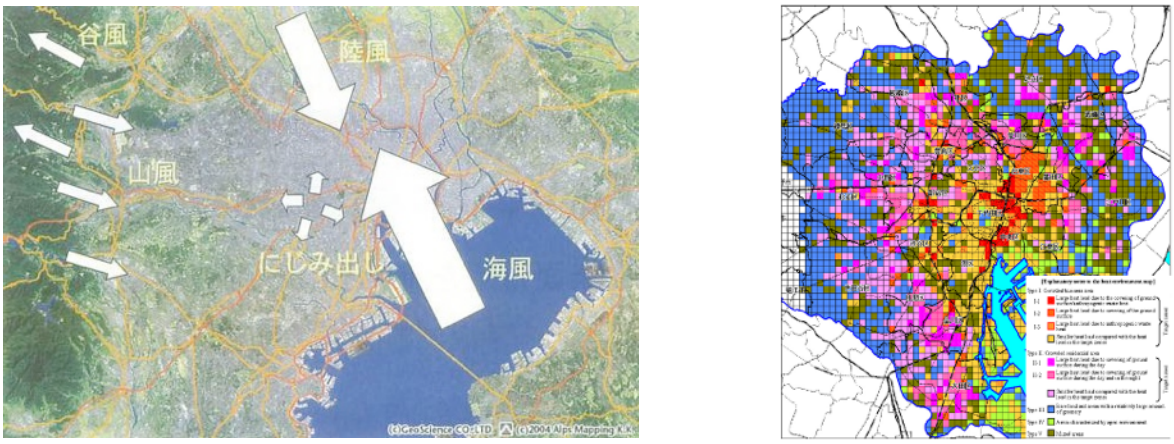

Figure 4: a) Wind system in Tokyo Metropolitan(三上岳彦, 2006); b) Thermal Environment Map for Tokyo Metropolitan (Tokyo Metropolitan Gov., 2003)

German UC-ReMap studies focus on transferring climatic understanding from UC-AnMap and give recommendations on three aspects: open space (including green space), settlement area (built-up area) and the areas highly related to the air exchange.

2.2 UCMap study in Japan

Most Japanese cities have experienced fast urbanization over the past half of century. Consequently, the environmental quality has been affected. Especially in the middle of the 1990s, the numbers of hot summer nights increased greatly and the Urban Heat Island (UHI) effect intensified strongly. So the public has been aware of the importance of urban environment. In the mean while, Japanese researchers have begun to adopt the method of UC-Map from Germany into local climatic studies and tried to use Klimaatlas[1] to find the possible and effective countermeasures. Considering Japanese cities' geographical characteristics, they took land-sea breeze into account (Figure 4a). Because most Japan cities are located along the coastline of Pacific Ocean and could be affected by land-sea breeze, which is largely different from German inland cities. At the initial stage of their studies, they are more focusing on the thermal environmental aspect for creating UC-AnMap, such as Thermal Environment Map for Tokyo Metropolitan (Figure 4b). One of their key interests is Anthropogenic Heat analysis. And in the later stage the wind information will be added into the study.

With more and more UC-Map information introduced to Japan, many Japanese cities began to conduct UC-Map studies, which are shown in the below Figure 5a. Among them, Tokyo Metropolitan and Osaka led a pioneer work in this field. In 2000, the Architectural Institute of Japan (AIJ) published “Klimaatals of Urban Environment-considering climatic information in city development (都市環境のクリマアトラス-気候情報を活かした都市づくり-)” (日本建築学会, 2000) (Figure 5b), which briefly reviewed the UC-Map development in Japan and offered several local case studies.

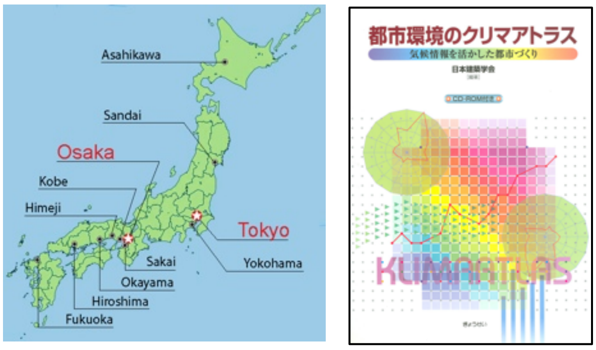

Figure 5: a) Japanese Cities conducting the UCMap studies;

b) “Klimaatals of Urban Environment-considering climatic information in city development (日本建築学会, 2000)

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[1] Klimaatlas: it is a German word meaning climatic atlas, which includes a series of maps with climatic and planning information, especially the UC-AnMap and UC-ReMap.

[2] CASBEE: Comprehensive Assessment System for Building Environmental Efficiency http://

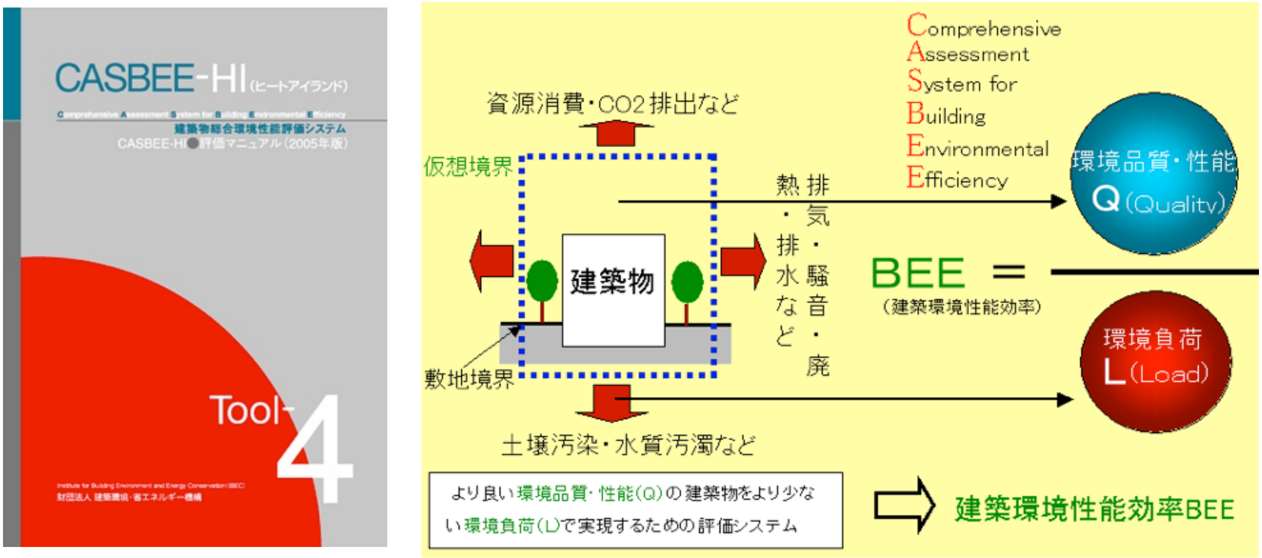


Figure 6: CASBEE–HI as an extension of CASBEE for assessing UHI relaxation measures

Besides this climatic study, Japanese researchers tried to use quantity method on analysis of heat island countermeasures in the building design. So in 2005, CASBEE-HI[2] is published by Japan Green Build Council (JGBC) and Japan Sustainable Building Consortium (JSBC) (Figure 6). It is a tool for detailed quantitative assessment of heat island relaxation measures in building design, which takes five items into count, such as Urban Ventilation, Shading, Ground Surface Covering Materials, Building Materials and Anthropogenic Heat Release from Building Facilities (Mochida, 2006).

Since 1999, Ministry of the Environment (ME) and Ministry of Land, Infrastructure and Transport (MLIT) of Japan Government have worked actively on this UC-Map study, which is mainly used for analyzing and mitigating Urban Heat Island Effect. In the conceptual diagram in Figure 7, UC-Map is thought as an important method of managing thermal environment (ヒートアイランド対策手法調査検討委員会 & 社団法人環境情報科学センター, 2002).

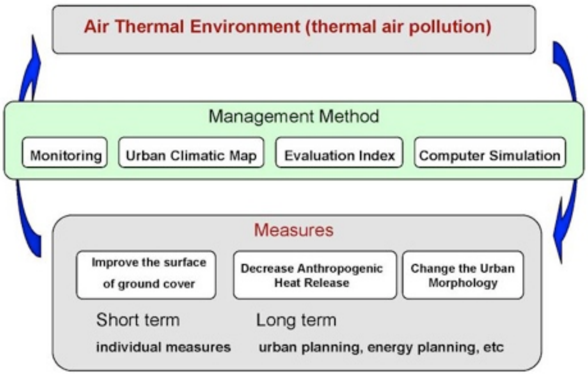


Figure 7 Urban Climatic Map's application in Air Thermal Environment Management in Japan (ヒートアイランド対策手法調査検討委員会 & 社団法人環境情報科学センター, 2002)

Then, in March 2004, they announced an outline of countermeasures against heat islands (ヒートアイランド対策大綱) (ヒートアイランド現象による環境影響調査検討委員会 & 環境情報科学センター, 2004) based on the findings from UC-Map. And in July 2004, MLIT issued building design guidelines for mitigating urban heat island effects（ヒートアイランド対策のための建築設計ガイドライン）. Since then, these two Ministries together hold on a series of meetings for all prefecture governors for introducing and promoting these study results into local actions (ヒートアイランド対策関係府省連絡会議), such as Eight Local Governments Action Plan (エコウェーブ, 八都県市地球温暖化防止一斉行動), which eight prefectures and cities around Tokyo Bay are involved in (Figure 8).

Currently, based on the findings from UC-Map study, recommendations on two aspects were offered for UHI mitigation. One is focusing on using urban green space. The other is by using air path. So recently, ME conducted further study on

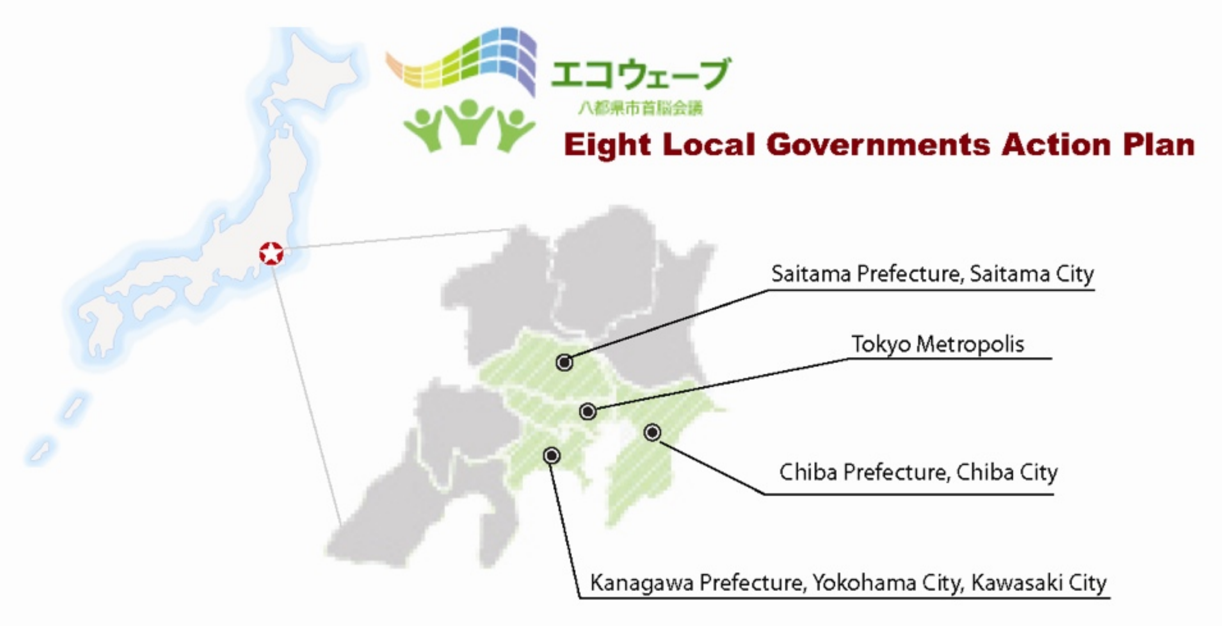


Figure 8: The prefectures and cities are in the Eight Local Governments Action Plan

how to use urban green space to improve the thermal environment (都市緑地を活用した地域の熱環境改善構想) from 2004(都市緑地を活用した地域の熱環境改善構想検討会, 2005; 都市緑地を活用した地域の熱環境改善構想検討会 & 環境情報科学センター, 2006). And since 2007 the committee of Eight Local Governments Action Plan has carried out an investigation on Air Path, (「風の道」に関する調査・研究業務) which took downhill movements, land-sea breeze and cooling effect from river and parks into account(八都県市首脳会議環境問題対策委員会幹事会, 2007).

3. Structure of UCMapping System

The UCMapping system consists of a series of basic input layers and two main UCMap components (Figure 9). The basic input layers contain analytical maps of climatic and

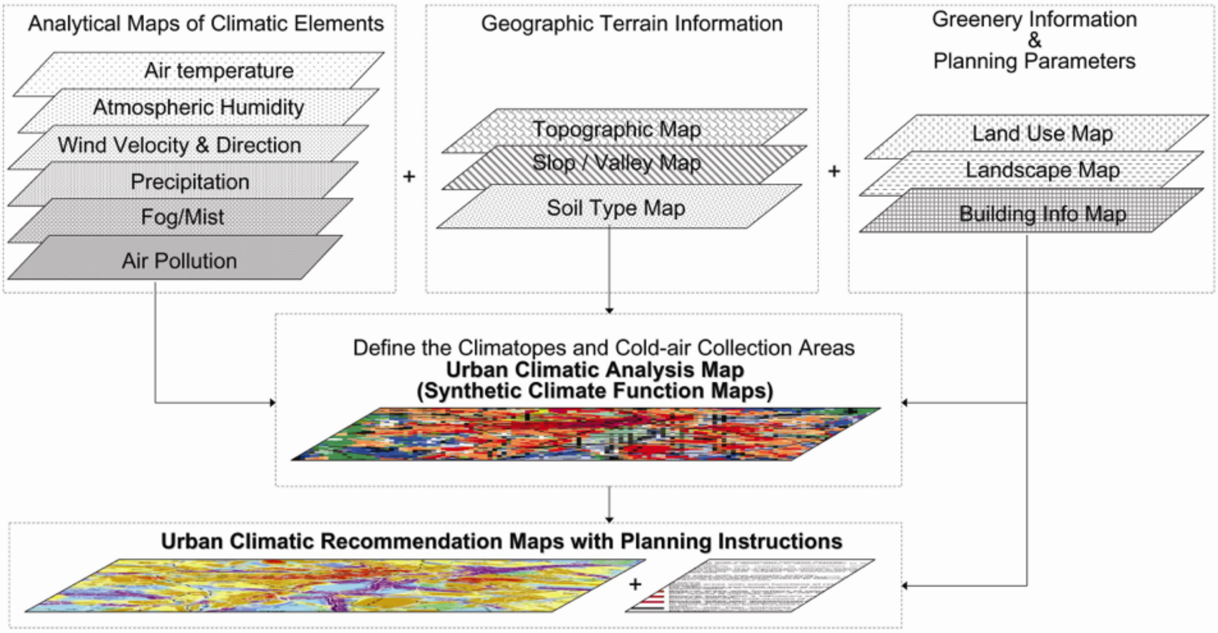
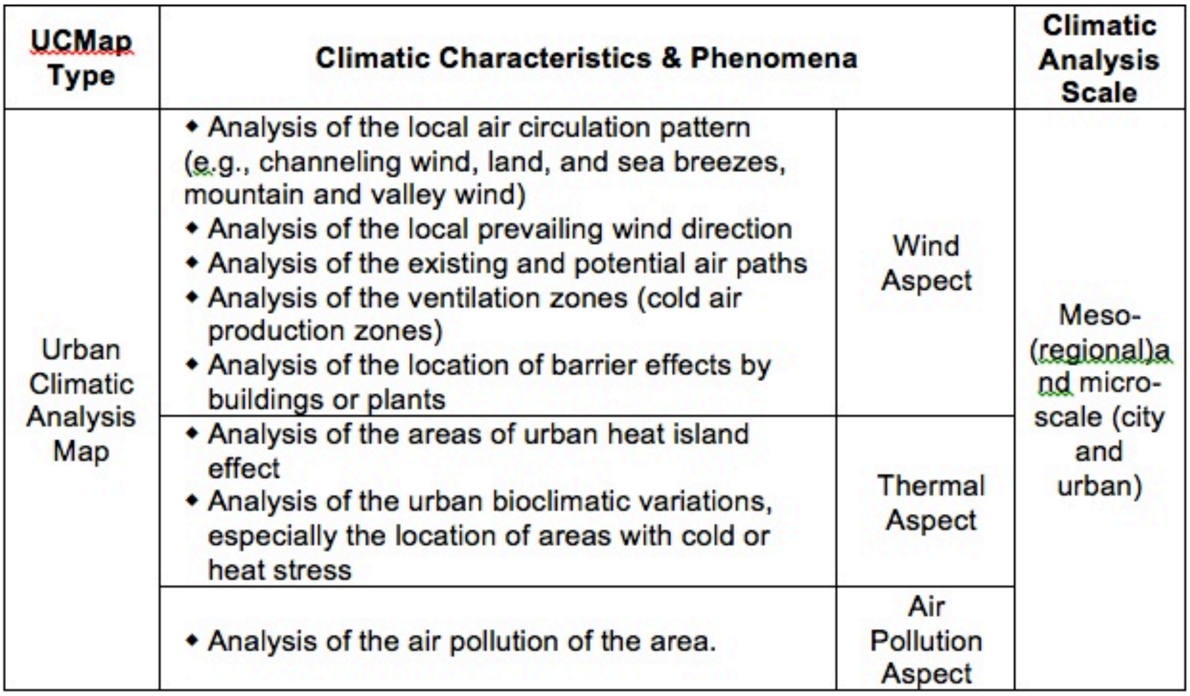


Figure 9: Structure of UCMap

Table 1 Climatic Analysis and Phenomena in an UCAnMap (Katzschner, 1998; VDI, 1997)



UCMap Type	Climatic Characteristics & Phenomena		Climatic Analysis Scale
Urban Climatic Analysis Map	◆ Analysis of the local air circulation pattern (e.g., channeling wind, land, and sea breezes, mountain and valley wind) ◆ Analysis of the local prevailing wind direction ◆ Analysis of the existing and potential air paths ◆ Analysis of the ventilation zones (cold air production zones) ◆ Analysis of the location of barrier effects by buildings or plants	Wind Aspect	Meso-(regional)and micro-scale (city and urban)
	◆ Analysis of the areas of urban heat island effect ◆ Analysis of the urban bioclimatic variations, especially the location of areas with cold or heat stress	Thermal Aspect	
	◆ Analysis of the air pollution of the area.	Air Pollution Aspect	

meteorological elements, geographic terrain data, greenery information, and planning parameters. There are two main UCMap components: the UC-AnMap, which visualizes and spatializes various climatic evaluation and assessment by different Climatopes; and the UC-ReMap, which includes planning instructions from the urban climatic point of view.

3.1 Urban Climatic Analysis Map (UC-AnMap)

UC-AnMap is also named as ”Synthetic Climatic Function Map”. It summarizes and synergizes scientific understanding of input climatic parameters and land data under certain scenarios (annual or specific seasonal condition). It can tell how the streets are ventilated; where are the more comfortable spots, where the problem areas are, and how the buildings are affecting the city wind environment(Ng et al., 2006). In Table 1, it shows the climatic analytical aspects of UC-AnMap including wind (ventilation), thermal environment and air pollution situation. Figure 10 shows HK UC-AnMap as example.

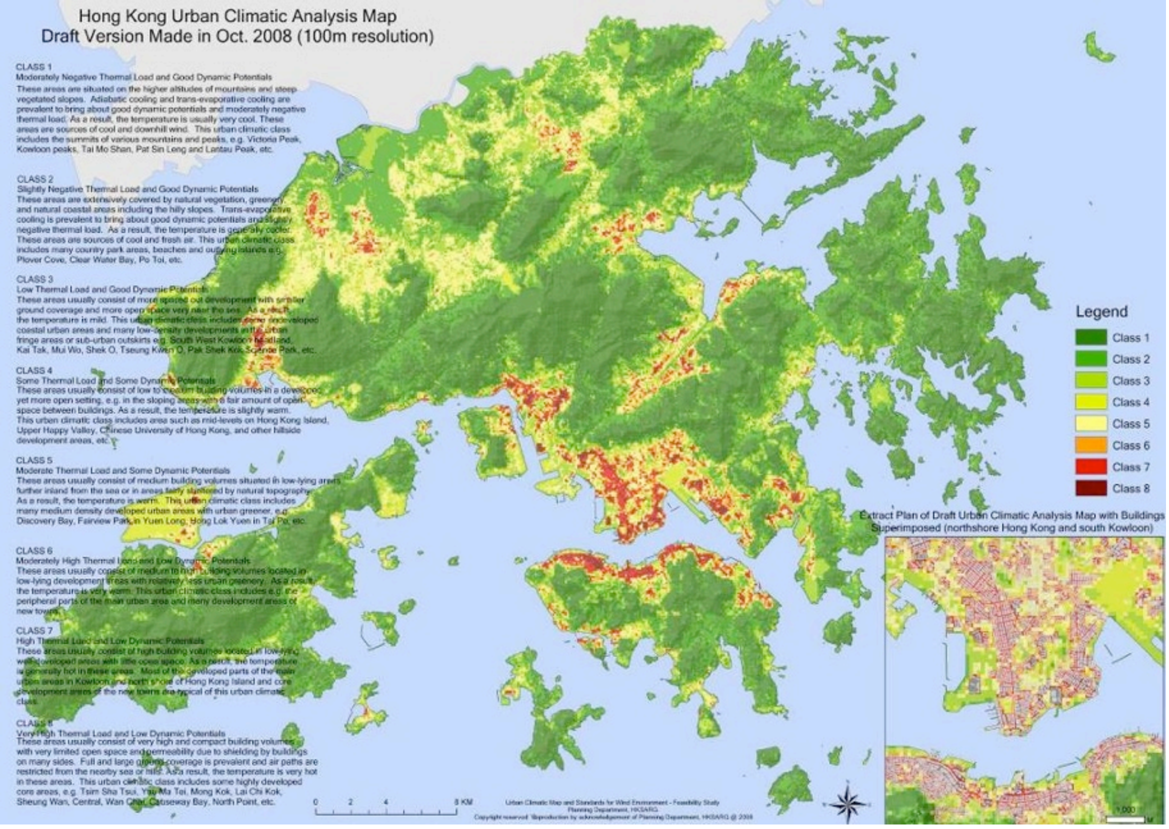
3.2 Urban Climatic Planning Recommendation Map (UC-ReMap)

The UC-ReMap is planning oriented. Based on the analysis obtained from the Urban Climatic Analysis Map (UC-AnMap), climatic zones and air paths could be developed. These areas of UC-ReMap are represented in different colors and symbols showing “Place which requires an improvement” and “Place which should be conserved” from the view of urban climate (Figure 11). Then, with the aim of mitigating the negative situation and protecting the positive situation, the planning advices and guidelines for each zone are offered by expert and planner. Since it is generated from Urban Climatic Analysis Map, in the process of developing, it needs to pay attention on the “climatic knowledge transferring” from UC-An Map to UC-Re Map and make sure the climatic information and the evaluation result correctly presenting in urban planning language. So in this stage urban climatologist and urban planner need to work closely and communicate from time to time.

Based on the literature of world-wide UC-AnMap and UC-ReMap studies, the summarized possible strategies could be conducted from the following four aspects, such as changing surface albedo, planting more vegetation, providing shadings for pedestrian, and improving urban ventilation situation (Figure 12).

4 Conclusion

Based on the available information collated, UCMap takes into account an expertly balanced evaluation of positive and negative effects of the



CLASS 1
Moderately Negative Thermal Load and Good Dynamic Potentials
These areas are situated on the higher altitudes of mountains and steep vegetated slopes. Adiabatic cooling and trans-evaporative cooling are prevalent to bring about good dynamic potentials and moderately negative thermal load. As a result, the temperature is usually very cool. These areas are sources of cool and downhill wind. This urban climatic class includes the summits of various mountains and peaks, e.g. Victoria Peak, Kowloon peaks, Tai Mo Shan, Pat Sin Leng and Lantau Peak, etc.

CLASS 2
Slightly Negative Thermal Load and Good Dynamic Potentials
These areas are extensively covered by natural vegetation, greenery, and natural coastal areas including the hilly slopes. Trans-evaporative cooling is prevalent to bring about good dynamic potentials and slightly negative thermal load. As a result, the temperature is generally cooler. These areas are sources of cool and fresh air. This urban climatic class includes many country park areas, beaches and outlying islands e.g. Plover Cove, Clear Water Bay, Po Toi, etc.

CLASS 3
Low Thermal Load and Good Dynamic Potentials
These areas usually consist of more spaced out development with smaller ground coverage and more open space very near the sea. As a result, the temperature is mild. This urban climatic class includes some undeveloped coastal urban areas and many low-density developments in the urban fringe areas or sub-urban outskirts e.g. South West Kowloon headland, Kai Tak, Mui Wo, Shek O, Tseung Kwan O, Pak Shek Kok Science Park, etc.

CLASS 4
Some Thermal Load and Some Dynamic Potentials
These areas usually consist of low to medium building volumes in a developed yet more open setting, e.g. in the sloping areas with a fair amount of open space between buildings. As a result, the temperature is slightly warm. This urban climatic class includes area such as mid-levels on Hong Kong Island, Upper Happy Valley, Chinese University of Hong Kong, and other hillside development areas, etc.

CLASS 5
Moderate Thermal Load and Some Dynamic Potentials
These areas usually consist of medium building volumes situated in low-lying areas further inland from the sea or in areas fairly sheltered by natural topography. As a result, the temperature is warm. This urban climatic class includes many medium density developed urban areas with urban greener, e.g. Discovery Bay, Fairview Park in Yuen Long, Hong Lok Yuen in Tai Po, etc.

CLASS 6
Moderately High Thermal Load and Low Dynamic Potentials
These areas usually consist of medium to high building volumes located in low-lying development areas with relatively less urban greenery. As a result, the temperature is very warm. This urban climatic class includes e.g. the peripheral parts of the main urban area and many development areas of new towns.

CLASS 7
High Thermal Load and Low Dynamic Potentials
These areas usually consist of high building volumes located in low-lying well-developed areas with little open space. As a result, the temperature is generally hot in these areas. Most of the developed parts of the main urban areas in Kowloon and north shore of Hong Kong Island and core development areas of the new towns are typical of this urban climatic class.

CLASS 8
Very High Thermal Load and Low Dynamic Potentials
These areas usually consist of very high and compact building volumes with very limited open space and permeability due to shielding by buildings on many sides. Full and large ground coverage is prevalent and air paths are restricted from the nearby sea or hills. As a result, the temperature is very hot in these areas. This urban climatic class includes some highly developed core areas, e.g. Tsim Sha Tsui, Yau Ma Tei, Mong Kok, Lai Chi Kok, Sheung Wan, Central, Wan Chai, Causeway Bay, North Point, etc.

Figure 10: The UC-AnMap of Hong Kong(Ng et al., 2008)

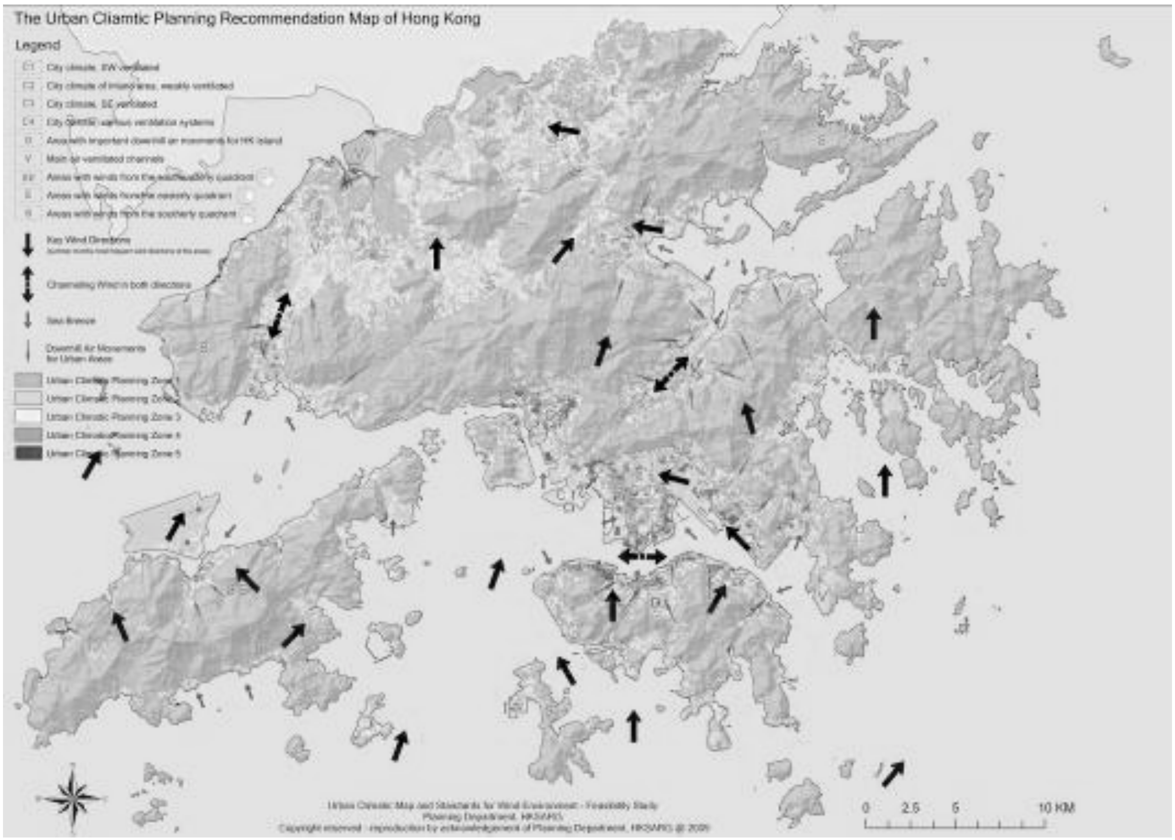


Figure 11: The UC-ReMap of Hong Kong(Ng et al., 2009)[3]

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[3] Due to the sensitivity of Figure 11, it only can be presented in grey colour at current stage.

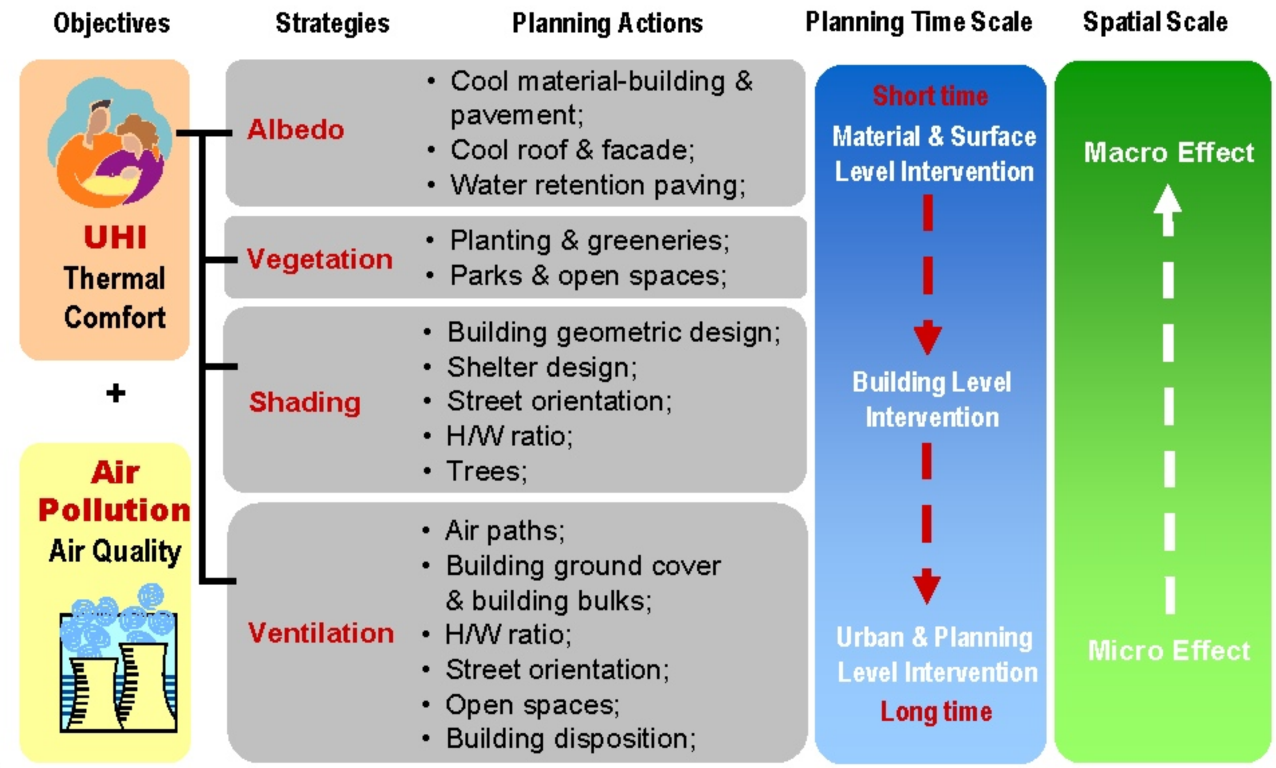


Figure 12: Lessons on strategies and measures for improving urban climate environment

local climate, topography of the land, vegetation and buildings of the city, and wind patterns. In the planning aspect, this approach provides an evaluation tool that makes use of available spatial data, and proposes solutions for planning use through knowledge-based expert evaluation. The advantages of UCMap should be noticed: UCMap is a cross-disciplinary study and practice; climatic phenomenon and data are visualized by colours and graphics presented with spatial information in mapping format, which is easily understood by planners, architects and policy makers; climatic problematic and sensitive areas are observable using UCMap. In the mean while, the limitation of UCMap also can be found: the result of UCMap studies depends not only objectively and empirically collected data, but also rely on the expert's experience and qualitative evaluation; the UCMap study needs a better and more quantitative procedures and standardization method to balance and weight input data.

Since current UCMap studies focus on low density cities and more and more developing countries are facing fast urbanization, in future UCMap study should be conducted more in these countries, especially in those high density cities. With assistance of advanced techniques of Google earth and GIS, the future interface of UCMap should be easily accessed not only by the professionals of construction industry, but also by the general public. Given the climate change and human thermal comfort issues, climate change impact and the bioclimatic information should also be taken into account.

Acknowledgement

Authors are very grateful to Prof. Helmut Mayer, Prof. Andreas Matzarakis, Prof. Juergen Baumüller, Dr. Ulrich Reuter, Prof. Toshiaki Ichinose, Prof. Masakazu Moriyama and Dr. Yasunobu Ashie for their valuable suggestions and references. Authors also would like to thanks Planning Department of HK Government for providing the relevant data and Chinese University of Hong Kong for providing the necessary academic support to complete this research.

REFERENCES

Baumüller, J., Hoffmann, U., & Reuter, U. 1992. Climate booklet for urban development, Ministry of Economy Baden-Wuerttemberg (Wirtschaftsministerium), Environmental Protection Department (Amt für Umweltschutz).

Chandler, T.J. 1976. Urban Climate and Its Relevance to Urban Design. WMO, Technical No.

149, World Meteorological Organization, : Genveva, Switzerland.

Katzschner, L. 1998. Designation of urban climate qualities and their implementation in the planning process. Paper presented at the ENVIRONMENTALLY FRIENDLY CITIES, PLEA'98. 75-78, James & James Science Publishers Ltd., Lisbon, Portugal,

Lüttig, G.W. 1972. Naturräumliches Potential I, II und II. In Niedersachsen, Industrieland mit Zukunft, (pp. 9-10). hannover.

Lüttig, G.W. 1978a. Geoscientific maps for land-use planning. A certain approach how to communicate by new types fo maps. In Internat. Yearb. Cartogr, (Vol. 18, pp. 95-101). Godesberg, Germany: Bonn-Bad.

Lüttig, G.W. 1978b. Geoscientific maps of the environment as an essential tool in planning. Geol. en Mijnb, 57 (4): 527-532.

Matzarakis, A. 2005. Country Report: Urban Climate Research in Germany, IAUC Newsletter 11: 4-6.

Mochida, A. 2006. Comprehensive Assessment System for Building Environmental Efficiency on Heat Island Relaxation: CASBEE-HI. Paper presented at the International Workshop on Countermeasures to Urban Heat Islands, Internation Energy Agency (IEA) with the Japanese Ministry of Land, Infrastructure and Transport, Tokyo, Japan, from www.iea.org/Textbase/work/2006/heat/10-a_Mochida.pdf

Ng, E., Katzschner, L., Wang, Y., Ren, C., & Chen, L. 2008. Working Paper No. 1A : Draft Urban Climatic Analysis Map - Urban Climatic Map and Standards for Wind Environment - Feasibility Study, Technical Report for Planning Department HKSAR, Planning Department of Hong Kong Government, Hong Kong.

Ng, E., Kwok, K., Sun, D., Yau, R., & Katzschner, L. 2006. Inception Report – Urban Climatic Map and Standards for Wind Environment – Feasibility Study, Technical Report for Planning Department HKSAR, Hong Kong: 60 pages.

Ng, E., Ren, C., Katzschner, L., & Sun, D. 2009. WP1B Urban Climatic Planning Recommendation Report – Urban Climatic Map and Standards for Wind Environment – Feasibility Study, Technical Report for Planning Department HKSAR: 40.

Page, J.K. 1976. Application of Building Climatology to the Problems of Housing and Building for Human Settlements, WMO-No. 441. Technical Note No.150,, World Meteorological Organization: Geneva, Switzerland.

Ren, C., Ng, E., & Katzschner, L. 2010. Urban climatic map studies: a review. International Journal of Climatology DOI: 10.1002/joc.2237 (in press).

Scherer, D., Fehrenbach, U., Beha, H.-D., & Parlow, E. 1999. Improved concepts and methods in analysis and evaluation of the urban climate for optimizing urban planning process. Atmospheric Environment, 33: 4185-4193.

Sterten, A.K. 1982. A Thematic Mapping System and a Description of Local Climatic Conditions Developed for Urban Planning Purposes. Energy and Buildings, 4: 121-124.

VDI. 1997. VDI-Guideline 3787, Part 1, Environmental Meteorology-Climate and Air Pollution Maps for Cities and Regions, VDI, Beuth Verlag, Berlin.

WHO, & WMO. 1970. Urban climates. Secretariat of the World Meteorological Organization: Geneva.

ヒートアイランド現象による環境影響調査検討委員会, & 環境情報科学センター, 社. 2004. 平成15年度　ヒートアイランド現象による環境影響に関する調査検討業務 報告書, 環境庁請負業務報告書, 日本環境省. 日本環境省, 東京, 日本.

ヒートアイランド対策手法調査検討委員会, & 社団法人環境情報科学センター. 2002. 平成13年度ヒートアイランド対策手法調査検討業務報告書（増補版）, 環境庁請負業務報告書, 日本環境省. 日本環境省, 東京, 日本.

八都県市首脳会議環境問題対策委員会幹事会. 2007. 「風の道」に関する調査・研究業務ー調査報告書, 日本.

三上岳彦. 2006. 風と緑の効果と活用したまちづくりー東京都内の「風の道」とヒートアイランド効果ー. 季刊環境研究, 141

日本建築学会 (Ed.). 2000. 都市環境のクリマアトラス-気候情報を活かした都市づくり-. 東京,日本: 行政学会印刷所.

都市緑地を活用した地域の熱環境改善構想検討会. 2005. 平成16年度　都市緑地を活用した地域の

熱環境改善構想の検討（中間報告），環境庁請負業務報告書, 日本環境省. 日本環境省, 東京, 日本.

都市緑地を活用した地域の熱環境改善構想検討会, & 環境情報科学センター, 社. 2006. 平成17年度都市緑地を活用した地域の熱環境改善構想の検討調査報告書，環境庁請負業務報告書, 日本環境省. 日本環境省, 東京, 日本.

Application of Urban Climatic Map to Urban Planning of High Density Cities – An Experience from Hong Kong

Edward Ng, Chao Ren and Lutz Katzschner

High density and compact city design is a topical issue. There are needs to deal with the scarcity of land, to design for a viable public transport system, and to re-build the community of our inner cities. High density living is increasing an issue that planners around the world have to deal with. Hong Kong is a high density city with a population of 8 millions living on a piece of land of around 1,000 square kilometres. The urban (city) density of Hong Kong is around 60,000 to 100,000 persons per square kilometre. When the roads, open spaces and so on are taken away, for residential developments, the estate (site) development density of a piece of land in the city can be up to 3000 to 4000 persons per hectare. In a nutshell, it means that there are a lot of people, and therefore activities happening per square metre of land and its air space in a high density city. Moreover, urban Hong Kong has been multi-zoned. That is to say, commercial, amenity, residential, and sometimes industrial buildings are mixed and co-exist in close proximity.

Recently, the general public of Hong Kong is increasing aware of “over development” and “poor designs” of recently completed estates and projects. In order to maximise the site’s own aspects, sea view and hence profitability, property developers tends to construct high rise towers that occupy the frontage of the site thus forming tall and wide slab blocks. These blocks, aptly termed “Wall Buildings” by the locals, are “effective” wind blocks that seriously restrict the flow of air ventilation of the city (Figure 1). With lower air mass transport through the city, the dynamic potentials to mitigate urban heat island are seriously reduced; thermal stresses in the summer months are increased; and air pollutions dispersion is reduced. All in all, an unfavourable outdoor urban condition has resulted.

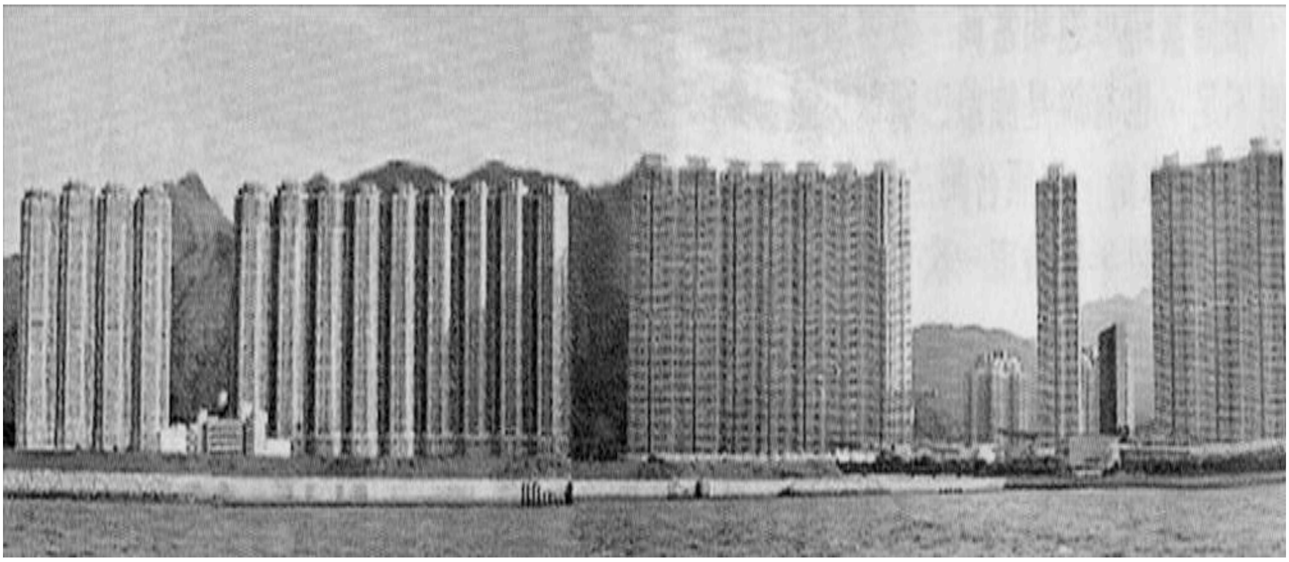


Figure 1: An example of wall building on the waterfront in Hong Kong

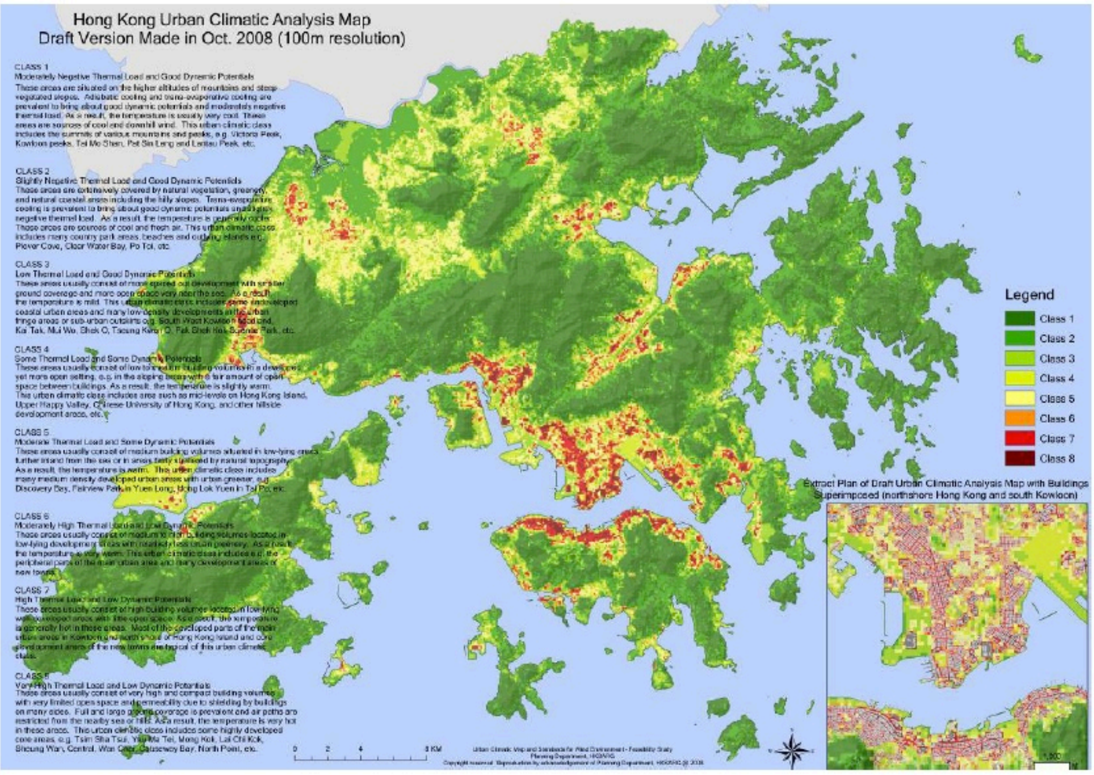


Figure 2: The Urban Climatic Analysis Map of Hong Kong

Finding ways to strategically plan a city environmentally requires climatic information that is scientifically based. Hong Kong is a high density city with a sub-tropical climate and a hilly topography. The government of Hong Kong has recently commissioned studies towards producing an Urban Climatic Map (UCMap) (Figure 2).

The categorization and grouping are by magnitudes of their positive dynamic potentials and negative thermal load effects. Urban climatically valuable areas should be preserved. Planning actions and mitigations should be directed to climatic zones that are critical and important, most particularly, the highly climatically sensitive areas.

Moderately Negative Thermal Load and Good Dynamic Potentials (Class 1) These areas are situated on the higher altitudes of mountains and steep vegetated slopes. Adiabatic cooling and trans-evaporative cooling are prevalent to bring about good dynamic potentials and moderately negative thermal load. As a result, the temperature is usually very cool. These areas are sources of cool and downhill wind. This urban climatic class includes the summits of various mountains and peaks.

Slightly Negative Thermal Load and Good Dynamic Potentials (Class 2) These areas are extensively covered by natural vegetation, greenery, and natural coastal areas including the hilly slopes. Trans-evaporative cooling is prevalent to bring about good dynamic potentials and slightly negative thermal load. As a result, the temperature is generally cooler. These areas are sources of cool and fresh air. This urban climatic class includes many country park areas, beaches and outlying islands.

Low Thermal Load and Good Dynamic Potentials (Class 3) These areas usually consist of more spaced out developments with smaller ground coverage and more open space very near the sea. As a result, the temperature is mild. This urban climatic class includes some undeveloped coastal urban areas and many low-density developments in the urban fringe areas or sub-urban outskirts.

Some Thermal Load and Some Dynamic Potentials (Class 4) These areas usually consist of low to medium building volumes in a developed yet more open setting, e.g. in the sloping areas with a fair amount of open space between buildings. As a result, the temperature is slightly warm.

Moderate Thermal Load and Some Dynamic Potentials (Class 5) These areas usually consist of medium building volumes situated in low-lying areas further inland from the sea or in areas fairly sheltered by natural topography. As a result, the temperature is warm. This urban climatic class includes many medium density developed urban areas with urban greenery.

Moderately High Thermal Load and Low Dynamic Potentials (Class 6) These areas usually consist of medium to high building volumes located in low-lying development areas with relatively less urban greenery. As a result, the temperature is very warm.

High Thermal Load and Low Dynamic Potentials (Class 7) These areas usually consist of high building volumes located in low-lying well-developed areas with little open space. As a result, the temperature is generally hot in these areas.

Very High Thermal Load and Low Dynamic Potentials (Class 8) These areas usually consist of very high and compact building volumes with very limited open space and permeability due to shielding by buildings on many sides. Full and large ground coverage is prevalent and air paths are restricted from the nearby sea or hills. As a result, the temperature is very hot in these areas.

The extraordinary urban morphology of Hong Kong and the complex wind environment makes the task a unique scientific challenge. Using planning and land use data, a GIS based UCMap has been created. Land uses, ground coverage, building bulk, greenery intensities, topography, and so on have been incorporated. Wind data is available from the Observatory, as well as simulated using MM5/CALMET (Figure 3). CFD simulations, wind tunnel tests, field studies and user surveys have been conducted. The map, targeted for 1:5000 scale planning will be referred to by planners when making strategic planning decisions for the future (Figure 4 and 5).

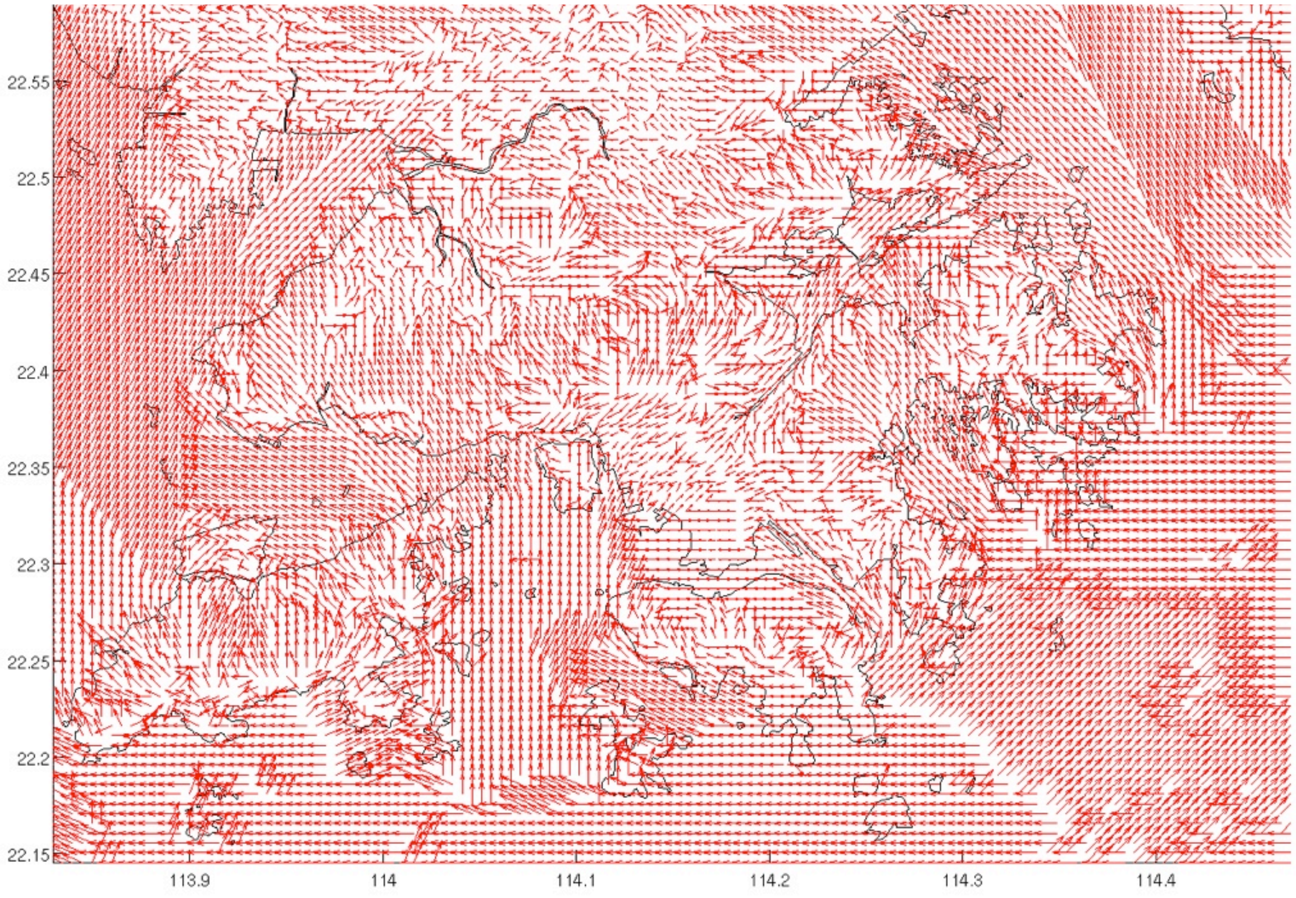


Figure 3: A MM5/CALMET wind simulation of the summer months of Hong Kong. The arrows showing the prevailing wind directions.

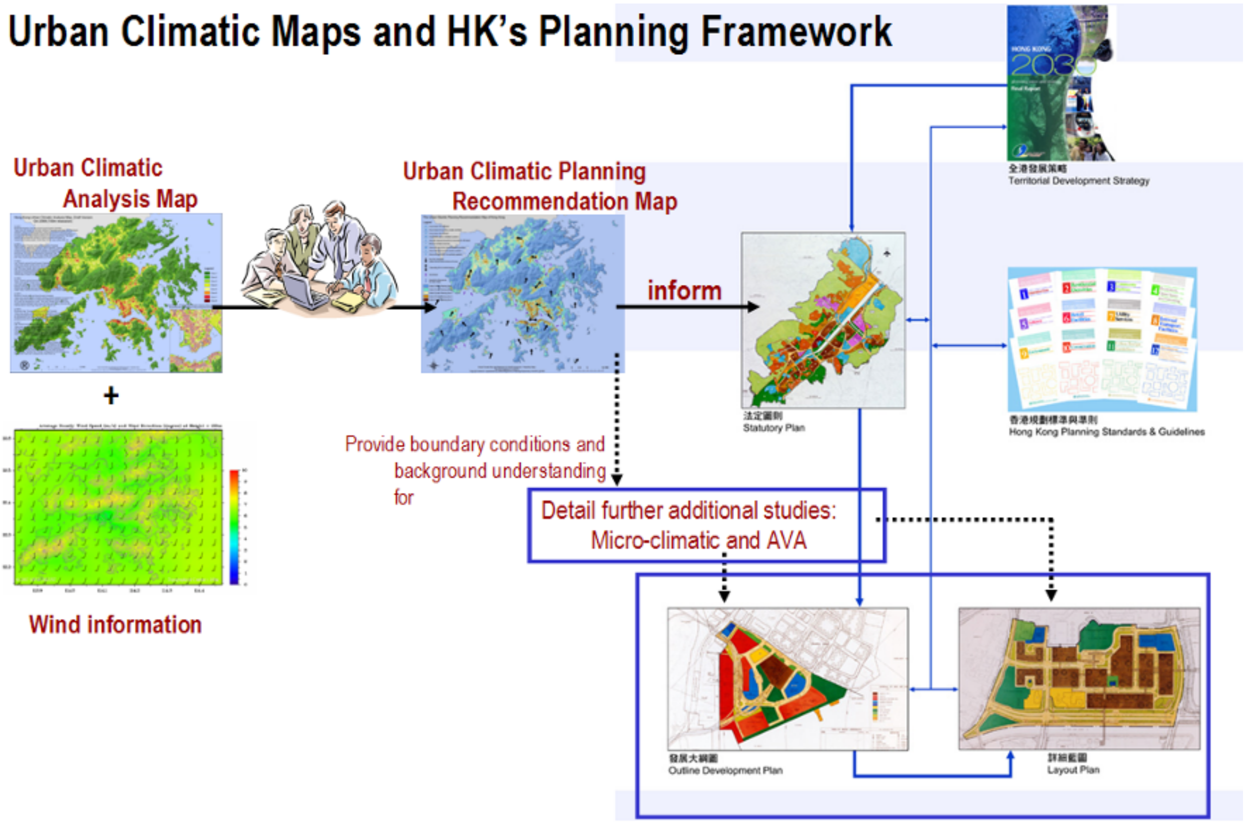


Figure 4: Urban Climatic Maps and Hong Kong's planning framework.

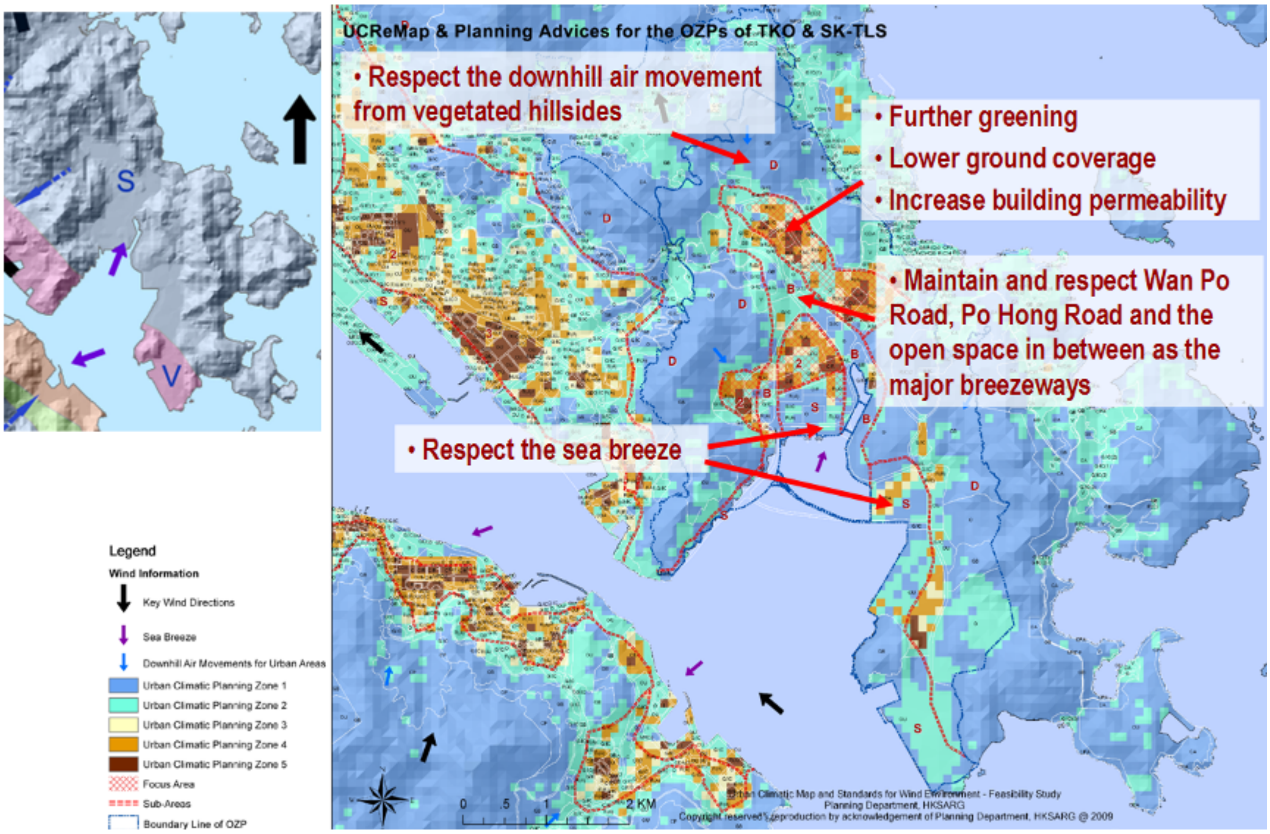


Figure 5: Planning recommendations based on the Urban Climatic Maps.

To illustrate, an area of urban Hong Kong (Figure 6) has been studied and is presented as below.

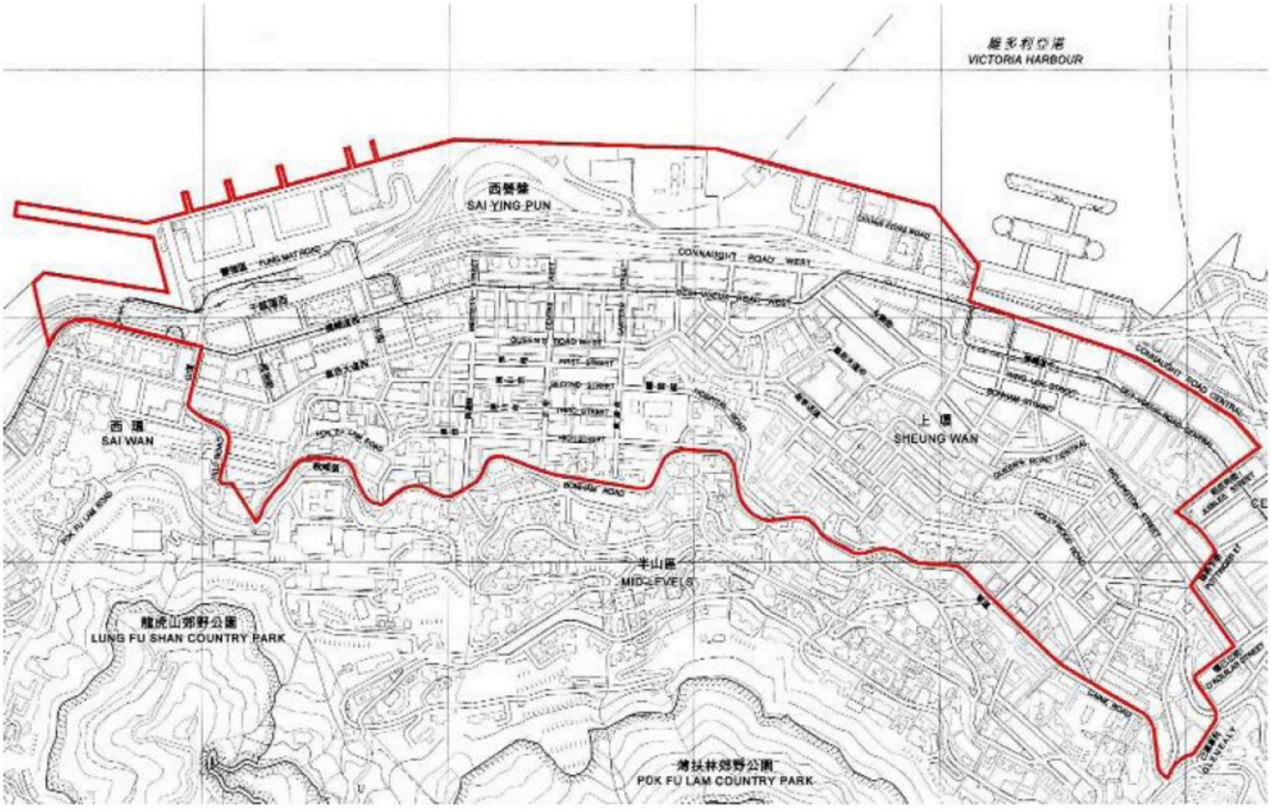


Figure 6: The urban area of Sheung Wan on the northern shore of the Hong Kong Island.

(a) The annual prevailing wind of the Sai Ying Pun and Sheung Wan Area is mainly from the East and North-East. The summer wind is mainly coming from the East and the Southerly quarters (Figure 7).

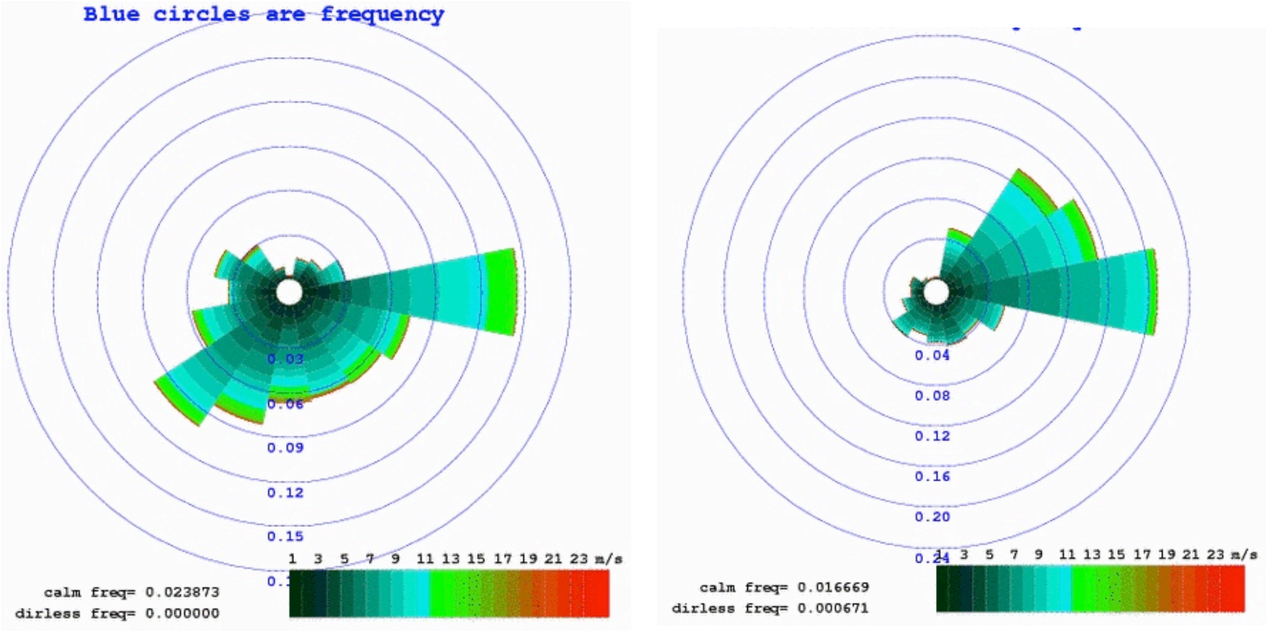


Figure 7: Wind roses in the summer (left) and annually (right) at 120m above ground, based on MM5/CALMET simulation study.

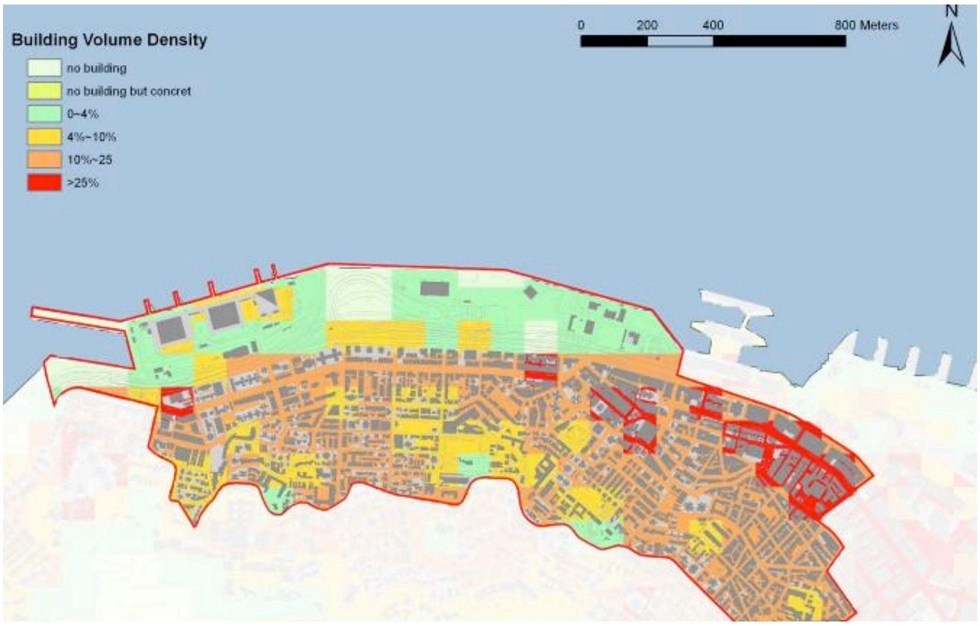


Figure 8: A building volume density study of the area.

(b) The Area has high building volume (Figure 8), building site coverage is high, there is a lack of open space, and streets are narrow. The air ventilation on the whole is poor.

(c) Tall and closely packed buildings along obstructs winds from the Victoria Habour coming into the Area (Figure 9). Few useful and direct north-south air paths of the Area means that it is difficult for winds from the waterfront to reach the inland areas.

(d) Tall and closely packed building of the Central District obstructs winds from the east (Figure 9). The main streets and roads that are parallel to the wind flow, for example, Des Voeux Road West, Queen's Road West Second Street and High Street are air paths of the Area. However, they are rather narrow and their efficacy is not high.

(e) The tall and closely packed buildings in Mid-levels West and the lack of air path obstruct a lot of the useful southerly summer winds reaching the Area (Figure 9).

(f) "Air spaces" like the Central Police Station; Hollywood Road Police R & F Married Quarters; the collection of Caine Road Garden, Caine Land Garden and Blake Garden; Hollywood Road Park; and King George V Memorial Park are very useful to the Area and should be kept and enhanced.

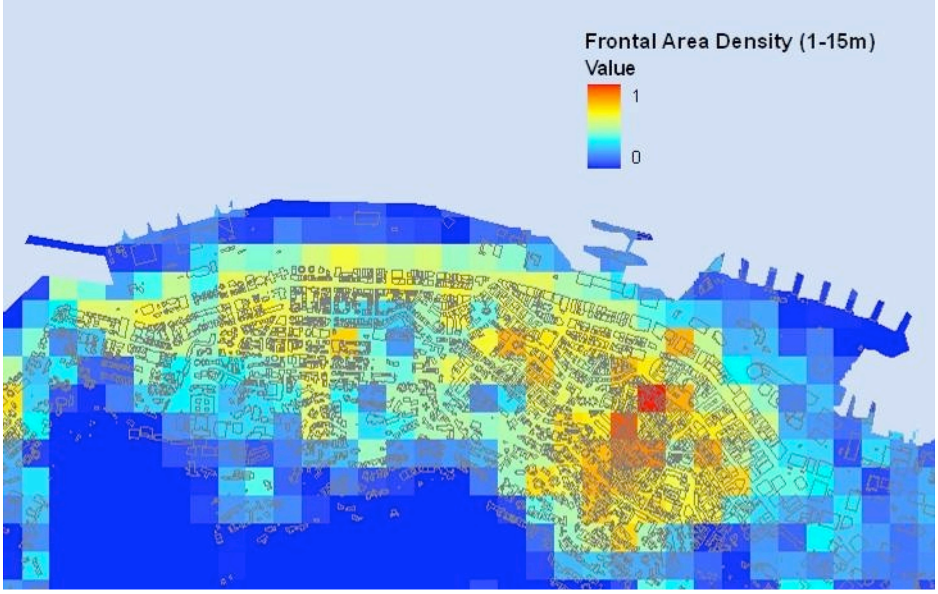
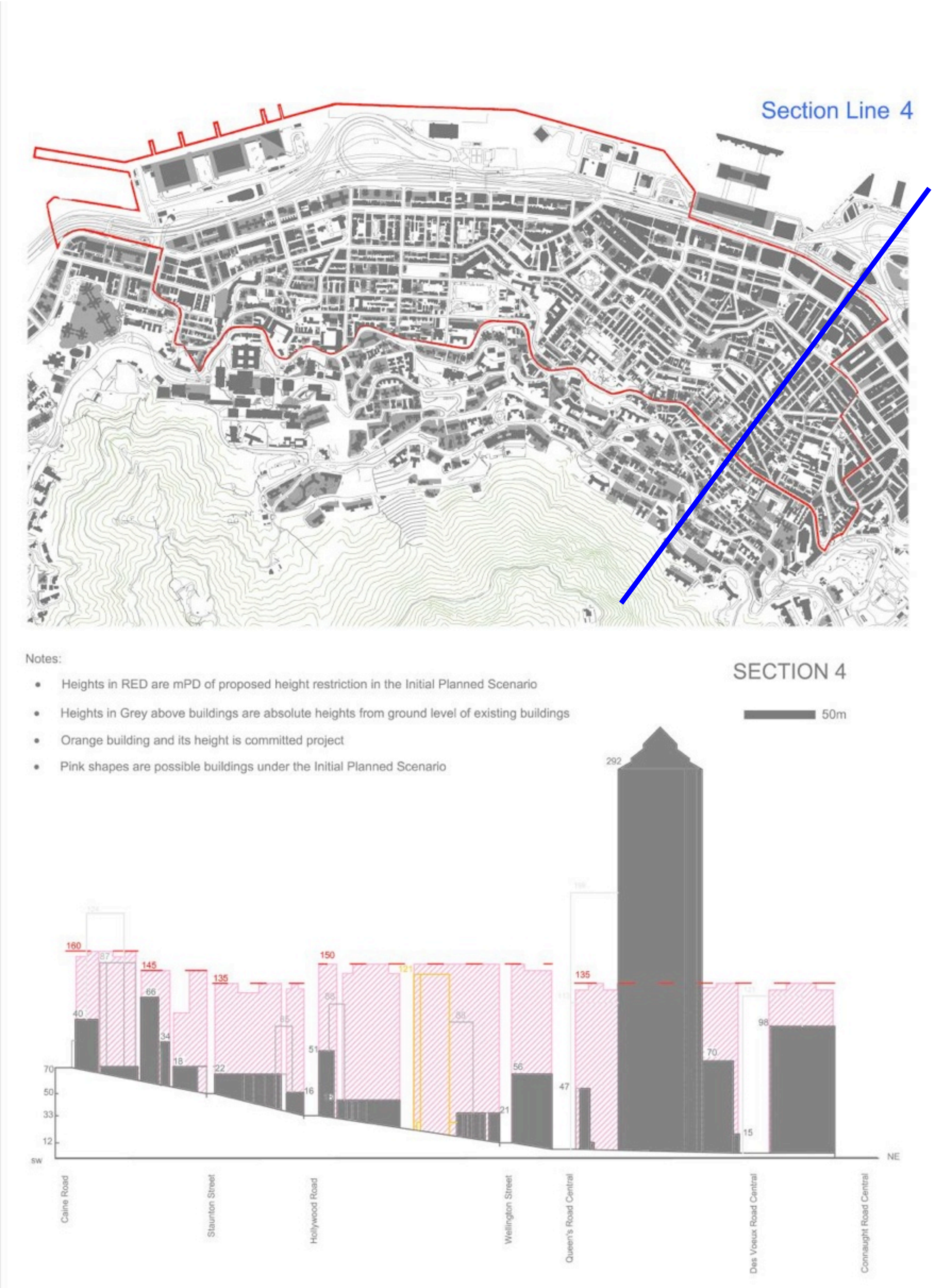


Figure 9: Frontal Area Density of the Study Area at height band 1 – 15m level.

(g) The Area is beginning to be "over developed". Care must be exercised with further potential re-development so as not to worsen the area's air ventilation.

(h) Indiscriminate further re-development adding building volume with tall and bulky buildings that occupy the entire Area, that would result in high building height to street width ratio (H/W) will further worsen the air ventilation of the Area and is not recommended.

(i) The stepped height concept of the Initial Planned Scenario would result in very deep and extensive street canyons – in the order of 10:1 (Figure 10). Without corresponding mitigation measures to alleviate the situation, the air ventilation would be further deteriorated.



Notes:

- Heights in RED are mPD of proposed height restriction in the Initial Planned Scenario
- Heights in Grey above buildings are absolute heights from ground level of existing buildings
- Orange building and its height is committed project
- Pink shapes are possible buildings under the Initial Planned Scenario

Figure 10: The deep canyons that may result if over-development continuous

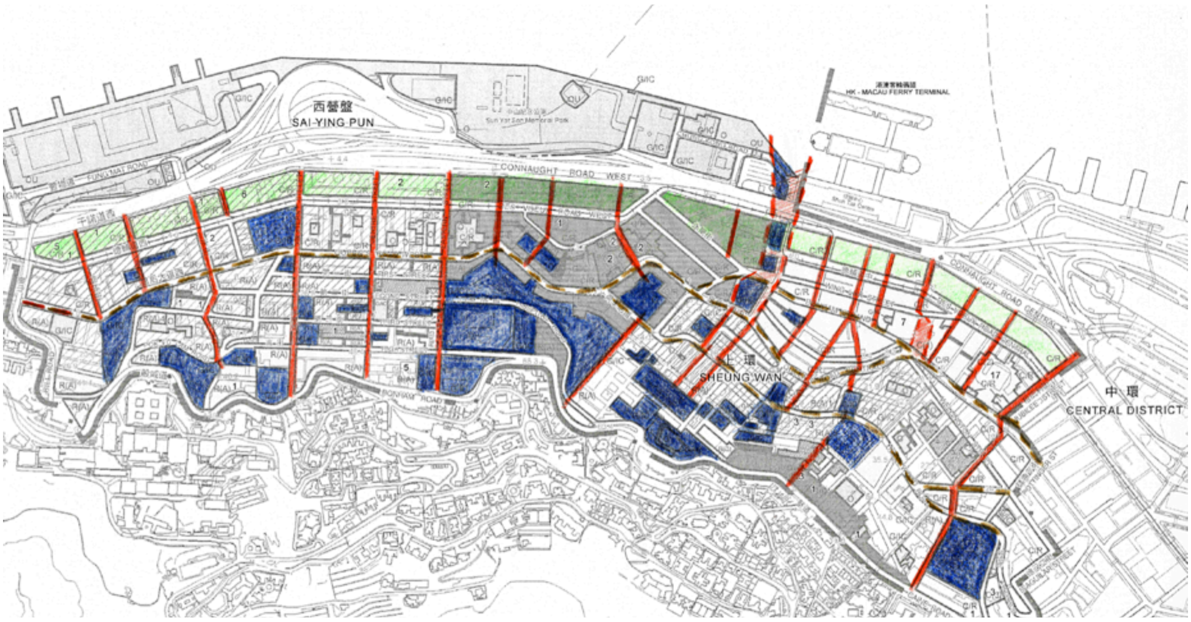
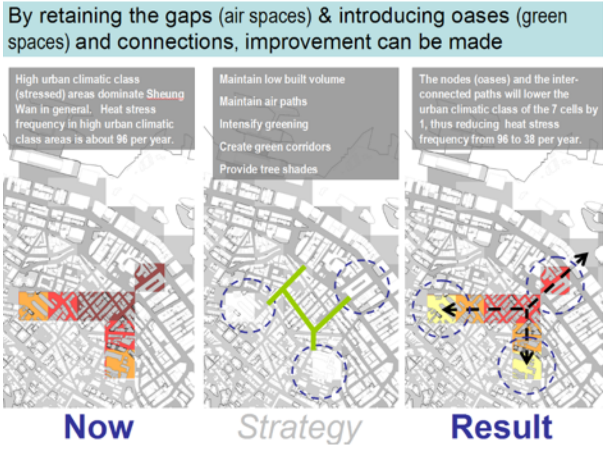


Figure 11: Open spaces (blue) and air paths (red lines) suggested for the area.



By retaining the gaps (air spaces) & introducing oases (green spaces) and connections, improvement can be made

High urban climatic class (stressed) areas dominate Sheung Wan in general. Heat stress frequency in high urban climatic class areas is about 96 per year.

Maintain low built volume

Maintain air paths

Intensify greening

Create green corridors

Provide tree shades

The nodes (oases) and the inter-connected paths will lower the urban climatic class of the 7 cells by 1, thus reducing heat stress frequency from 96 to 38 per year.

Figure 12: A planning recommendation for the study area.

Central Market provides an opportunity for Sheung Wan, the green oasis is a strategic start

The provision of a Green Oasis where it is most needed

Figure 13: A green oasis to be created in the area.

(j) Building along the waterfront must not occupy the entire site frontage. A 20-30% NBA is recommended.

(k) All north-south streets and lanes from Connaught Road West southwards must be widened.

(l) For east-west air ventilation, it is suggested that Queen's Road West and Queen's Road Central be widened. In addition, in Sheung Wan, Bonham Strand and Hollywood Road are suggested to be similarly widened.

(m) North-south air paths (red lines in Figure 6.4) that extend southward from the waterfront are useful.

(n) The GIC and O zone sites along the air paths are important providing air space to the study area and enhance the efficacy of the air paths (Figure 11). They must be maintained and enhanced. Further greening and tree planting is necessary.

(o) Major "Air spaces" like the Central Police Station; Hollywood Road Police R & F Married Quarters; the collection of Caine Road Garden, Caine Land Garden and Blake Garden; Hollywood Road Park; and King George V Memorial Park should be kept and enhanced. Further greening and tree planting is necessary (Figure 12 and 13).

All in all, the paper demonstrates how urban climatic considerations can be factored into planning decision making by using graphical tools like the urban climatic maps. In Hong Kong, the maps are valuable visual tools for lay planners. They are also powerful tools for politicians explaining key development strategies to the general public.

Strategies for Urban Climate and Urban Development under Consideration of the Global Climate Change

Lutz Katzschner

1. Introduction

The problem of the increase global temperature is more intensive in urban structures. Heat load and heat stress situations got worse. Heat waves have a severe affect inside the urban heat island. Figure 1 shows the time development while in Figure 2 the areal distribution is seen.

Much is known about the urban heat island and its development. In tall the global climate change scenarios with the respective downscaling methods a shift in heat load situation especially in cities due to the radiation and ventilation factors is observed. Mitigation factors urgently needed.

So one perspective in urban climate is the introduction of green and vegetation concepts to reduce heat stress, but more quantitative data are needed in order to justify the measures. Main effects are seen in green facades, changing of surfaces and the linkage of green in cities.

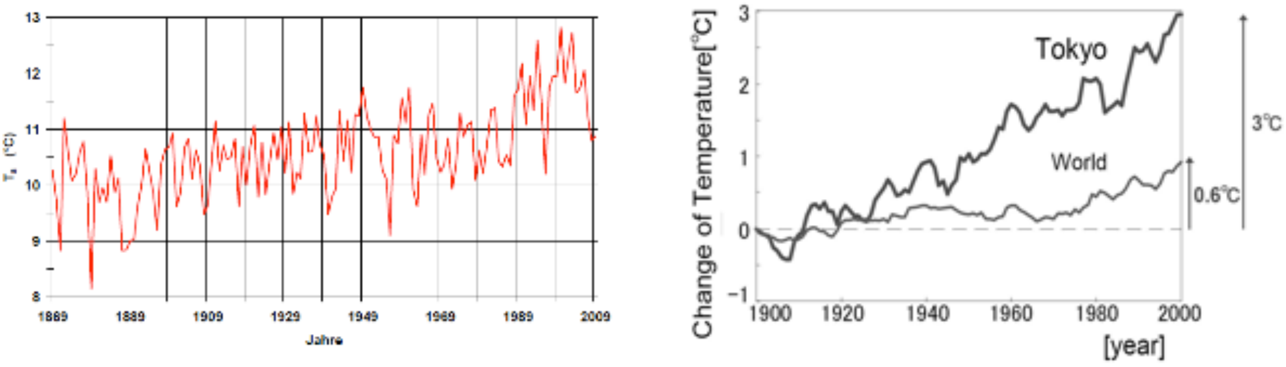


Figure 1: Air temperature increase and impact of cities

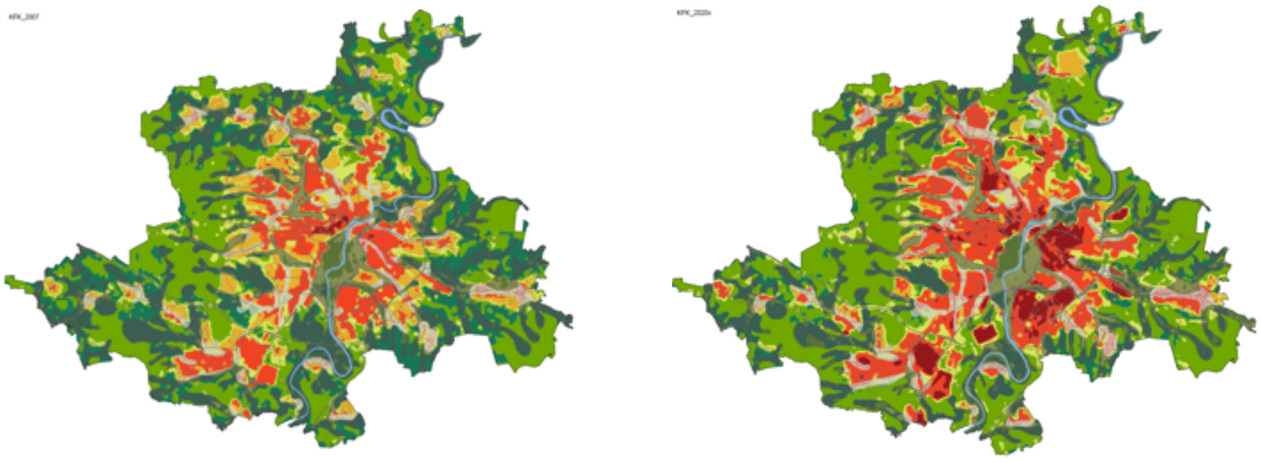


Figure 2: Urban climate map (heat island) of Kassel in the present situation (left) and in a 2030 scenario (right)

For any human-biometeorological evaluation the heat balance of man has to be considered. Ventilation and the short- and long wave radiation have the major effect but can also be easily influence and changes through vegetation. With rapid urbanization, there has been a tremendous growth in population and buildings in cities. The high concentration of hard surfaces triggered many environmental issues. The Urban Heat Island (UHI) effect and with it the urban thermal aspect the conditions in densely built cities were worsened. The primary root of UHI is the rapid urbanization which replaces natural landscape with enormous hard surfaces such as building facades, roads, pavements in cities. First, these hard surfaces in built environments re-radiate solar energy in the form of the long-wave radiation to surroundings. A lack of extensive vegetation further incurs the loss of a natural cooling means which cools surrounding air through evapotranspiration. Also, the UHI is aggravated by the lack of moisture sources due to the large fraction of these impervious surfaces in cities. The rain water is discharged quickly. Such increase in temperature and increase in long wave radiation with the presence of air pollutants can result in the accumulation of smog, damage the natural environment and jeopardize human health. It also costs consumers more money because it takes more energy to cool buildings. Green areas in cities are considered ecological measures for concrete jungles since plants can create an ‘oasis effect’ and mitigate the urban warming at both macro- and micro-level. As soon as a bare hard surface is covered with plants, the heat-absorbing surface transfers from the artificial layer to the living one. Leaves can seize most of the incoming solar radiation. For example, trees were observed to intercept 60% to 90% of the radiation (Lesiuk 2000). Except for a very small portion transformed into chemical energy through photosynthesis, most of the incident solar radiation can be transformed into the latent heat which converts water from liquid to gas resulting in a lower leaf temperature, lower surrounding air temperature and higher humidity through the process of evapo-transpiration. At night, the energy of the outgoing net radiation from a green surface is fed from the thermal heat flux and the latent heat flux. Therefore, the temperature around the green area is lower than that within the built environment.

2. Urban climate and urban green

Another aspect in urban climate and greenery is the human comfort in open spaces. In this respect research was carried out in a national program on climate change in cites with the influence on open space planning and an EU project RUROS. How to design open spaces in respect to urban climate. In figure 4 the results

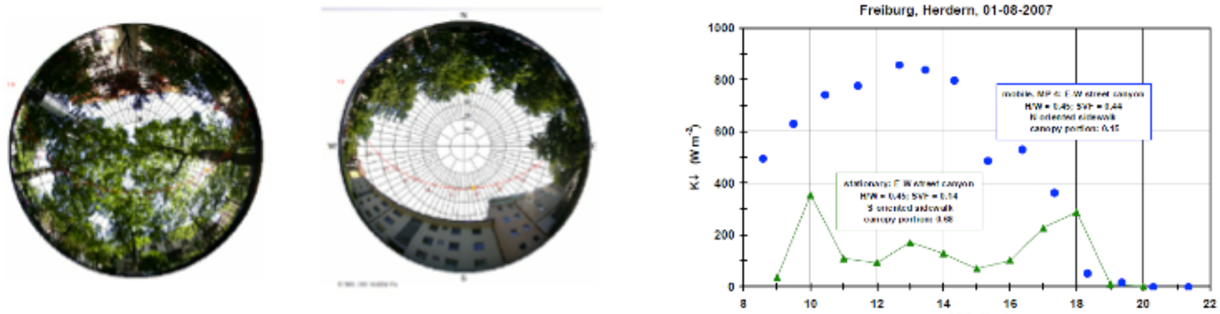


Figure 3: Effect of vegetation on radiation fluxes in cities

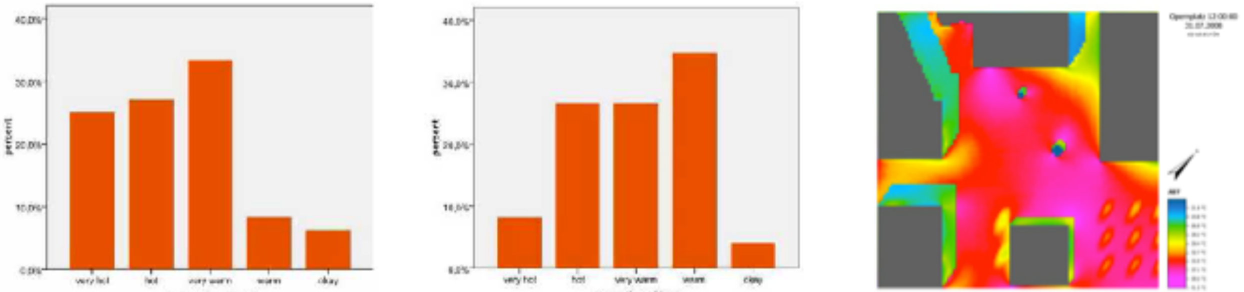


Figure 4: Thermal perception in course of time (Kassel/Germany) and the spational distribution for human comfort planning

from interviews combined with measurements show the switch of cooling from very warm to warm. This could be reached by vegetation shadow too.

Urban Parks

Although a single tree can already moderate the climate well, its impacts are limited to microclimate. Large urban parks can extend the positive effects to surrounding built environment. Within the park, it can be seen that most average temperatures were relatively lower than those measured in the residential blocks. From locations 1 to 4, the average temperatures range from 25.2 to 25.5°C. On the other hand, there is an orderly elevation of average temperatures for locations within the surrounding residential blocks. It shows that the park has cooling impact on the surroundings but it depends very much on the distance.

Road trees

Trees planted at road sides are very effective. The original purposes were to provide shading for pedestrians and for aesthetics. However, the thermal effect of road trees on surroundings cannot be ignored especially in an environment with low-rise buildings and mature trees.

Rooftop gardens

Plants strategically introduced into buildings can also benefit surrounding environment by reducing the ambient air temperature. The comparison of the external and the internal surface temperatures measured on the facades are important. Generally, the surface temperatures measured on the external walls were lower than those on the external walls of The differences can be around 1 to 2°C at night and around 4 to 8°C during the daytime. (Wong 2006) It could be concluded that by introducing greenery to the rooftop, the cooling energy consumption of a building can be reduced by about 20%. Even if this effect is located to the roof garden itself and does not influence the Urban Canopy layer in total the positive effect is seen on microscale level.

Vertical landscaping

In order to explore the shading effect of plants on facades, some pilot measurementswere carried out on some low-rise buildings where trees are planted closely to the facades (Wong 2006). The combined strategic introduction of plants on the facades save energy and at the same time reduce the long wave radiation and therefore lower the heat stress conditions.

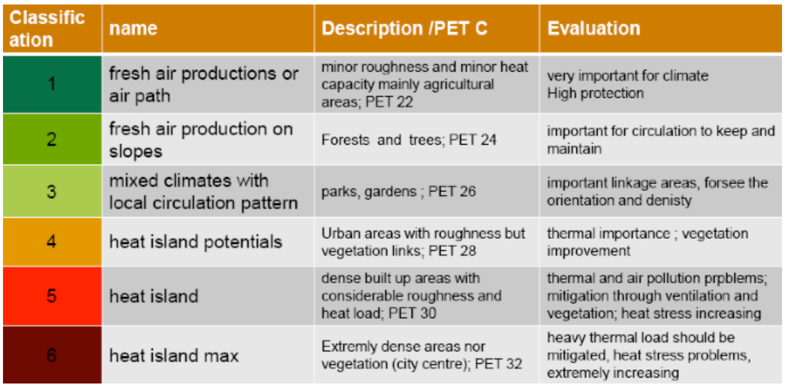
3. Recommendations

The urban heat island phenomena is not only for large or mega size cities. The mitigation effect of greenery has a very high dimension in the short and long wave radiation fluxes so that much can be done in urban planning.

Two main issues are not yet well understood:

- The quantification of thermal stress in open spaces, depending on the mesoscale conditions: percentage of greenery together with SFV or H/W dimensions and thermal comfort, development of a greenery factor with calibration
- The downscaling process from IPCC scenarios to urban climate

Therefore especially EU project could do research in the comparison of urban climate in different climate regions of Europe using the same methodology and therefore gets a quantifiable benchmark, which can be used in urban development and open space planning processes. Catagories from urban climatic maps can be done as follows:



Classification	name	Description /PET C	Evaluation
1	fresh air productions or air path	minor roughness and minor heat capacity mainly agricultural areas; PET 22	very important for climate High protection
2	fresh air production on slopes	Forests and trees; PET 24	important for circulation to keep and maintain
3	mixed climates with local circulation pattern	parks, gardens ; PET 26	important linkage areas, forsee the orientation and denisty
4	heat island potentials	Urban areas with roughness but vegetation links; PET 28	thermal importance ; vegetation improvement
5	heat island	dense built up areas with considerable roughness and heat load; PET 30	thermal and air pollution prpblems; mitigation through ventilation and vegetation; heat stress increasing
6	heat island max	Extremly dense areas nor vegetation (city centre); PET 32	heavy thermal load should be mitigated, heat stress problems, extremely increasing

REFERENCES

Chao, R.; Ng, E. Katzschner, L. 2010 Urban Climate Map Studies. A review, International Journal of Climatology, DOI: 10.1002/joc.2237

EU-RUROS 2004 Rediscovering the Urban Realm and Open Spaces - co-ordinated by CRES, Buildings Department. http://alpha.cres.gr/ruros

KLIMES 2009 Hitzestress im Stadtquartier - Identifizierung und Mitigation, BMBF, Koordination Universität Freiburg

Klimzug 2010 Klimaanpassung Mitte, Modellregion Nordhessen, Universität Kassel

Katzschner, L. 2010 Urban Climate in Dense Cities, in: Designing high-density cities, earthscan UK, ed: E. Ng, p. 71 - 83

Lesiuk, St. 2000 Biotecture II: Plant-building interaction. Retrieved 09 September 2000 from the World Wide Web: http://forests.org/ric/good_wood/biotctll.htm

Wong, N.H. 2006 Proceedings of PGBC Symposium 2006 Urban Climate + Urban Greenery December 2006, Hong Kong

London's urban climate: historical and contemporary perspectives

Sue Grimmond

Introduction

The history of urban climatology is linked in many ways to London. The origin of the field is widely attributed to Luke Howard[1] and his influential book 'The Climate of London'; London was the first global megacity and for hundreds of years has experienced many of the 'issues' that are now the stimulus for urban climate research – emissions, air quality, heat stress, sustainable development; and influential climatologists, Gordon Manley, Tony Chandler and Bruce Atkinson, for example, have worked in and on the city advancing how we measure, analyse and model urban climate. Here a brief overview is presented, structured around the issues that provided the rationale for the studies. All these issues persist today.

At the outset it is important to note two caveats. First, while examples of earlier work are presented these are not in any way exhaustive nor are they intended to be. Second, the focus here is on the physical nature of the urban atmosphere, particularly temperature, not its chemical composition; though the two are not independent, especially in the context of air quality.

Earliest concerns remain those of today - Urban Air Quality

Although human activities, most notably fire, have affected air quality for thousands of years, Helmut Landsberg (1981[2]) in his book cites Neumann (1979[3]) as identifying odes of Quintus Horatius Flaccus (about 24 B.C.) as the earliest reference. Landsberg's (1981) subsequent descriptions of air pollution all focus on London and attempts to ban coal burning in 1273, 1306 (King Edward I), by Queen Elizabeth I (1533-1603) for periods when Parliament was sitting, and John Evelyn's (1661[4], The Rota 1976[5]) attempts to influence Charles II.

John Evelyn was not successful in getting coal burning banned, but his 1661 publication provides an early description of air pollution in London (Chandler 1962[6], Landsberg 1981, Atkinson 1985[7]). Describing London as a 'city consisting of a wooden, northern, and inartificial congestion of houses; some of the principal streets so narrow, as there is nothing more deformed and unlike than the prospect of it at a distance, and its asymmetrie within the walls' (The Rota 1976 citing Everlyn 1659, p1). Evelyn recognised the link between urban air quality and urban form. He also became a Commissioner for the improvement of the City

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[1] Mark Howard L 2007. The Climate of London. IAUC edition available at www.lulu.com in two volumes

[2] Landsberg H (1981) The Urban Climate. Academic Press.

[3] Neumann J (1979) Air pollution in Ancient Rome. Bull Amer. Meteorol. Soc, 60,1097

[4] Evelyn J (1661) Fumifumigium or The Inconveniencie of the AER and SMOAK of LONDON DISSIPATED. With fome Remedies humbly proposed available: http://ia600204.us.archive.org/6/items/fumifugium00eveluoft/fumifugium00eveluoft.pdf

[5] The Rota (1976) Front pages in Evelyn (16615)

[6] Chandler TJ (1962) London's Urban Climate, The Geographical Journal 128, 279-98

[7] Atkinson BW (1985) The Urban Atmosphere. Cambridge University Press, 85 pp

streets and through this encouraged planting of trees in the Royal Parks (The Rota 1976). Following the Great Fire in September 1666 (when ca. 13,200 houses and a large number of churches and City of London buildings were destroyed), he again made recommendations about tree planting, but again without success (The Rota 1976).

These themes of urban morphology and the planting of trees both remain at the fore of urban air quality and health studies today. For example, a large research project funded by EPSRC and then the Home-Office, DAPPLE[8] (Dispersion of Air Pollution and its Penetration into the Local Environment) led by Alan Robbins, used a variety of techniques to study in detail 'the most polluted street in Europe' (Marylebone Road in London). Data were collected about the physical state of the atmosphere, exposure and ambient air quality, in conjunction with information on traffic (Arnold et al. 2004[9], Dobre et al. 2005[10], Tomlin et al. 2009[11], Wood et al. 2009[12]). These field measurements have been complemented with wind tunnel (hardware) and numerical modelling. Results show clearly that the dispersal of pollutants is highly dependent on the meteorological conditions (stability, and variability of the 3-d wind field) and morphology of the urban surface.

Tree planting is part of the current London Climate Change Adaption Strategy (GLA 2010a[13]) and the latest GLA (2010b[14]) air quality strategy for London 'Cleaning the Air'. Air quality is a major issue; the 2008 annual limit value of NO2 (40 µg m-3) was exceeded by 1287 km of road in 2008 in London (in 2010 947 km). Despite improvements it is anticipated it may take almost to 2025 to bring this to 0 km (Defra 2011[15]). As road traffic is the dominant source, London has introduced a low emission zone to reduce emissions; however, this remains highly contentious, with current Mayor Boris Johnson removing the western extension of the congestion charging zone.

Development and Deployment of Instruments

Before measurements of urban climates could begin instruments had to be developed and procedures for deployment were needed. Much of this was communicated through The Royal Society which was officially established in 1660[16]. In 1665 Hooke's Micrographia[17] included descriptions of

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[8] http://www.dapple.org.uk/

[9] Arnold SJ, H ApSimon, J Barlow, S Belcher, M Bell, JW Boddy, R Britter, H Cheng, R Clark, RN Colvile, S Dimitroulopoulou, A Dobre, B Greally, S Kaur, A Knights, T Lawton, A Makepeace, D Martin, M Neophytou, S Neville, M Nieuwenhuijsen, G Nickless, C Price, A Robins, D Shallcross, P Simmonds, RJ Smalley, J Tate, AS Tomlin, H Wang, P Walsh (2004) Introduction to the DAPPLE Air Pollution Project. Science of the Total Environment 332:139-153.

[10] Dobre, A., Arnold, S. J., Smalley, R. J., Boddy, J. W. D., Barlow, J. F., Tomlin, A. S. and Belcher, S. E. (2005) Flow field measurements in the proximity of an urban intersection in London, UK. Atmospheric Environment, 39 (26). pp. 4647-4657.

[11] Tomlin, A. S., Smalley , R. J., Tate, J. E., Arnold, S. J., Dobre, A., Barlow, J. F., Belcher, S. E. and Robins, A. (2009) A field study of factors influencing the concentrations of a traffic-related pollutant in the vicinity of a complex urban junction. Atmospheric Environment, 43 (32). pp. 5027-5037

[12] Wood, C. R., Arnold, S. J., Balogun, A. A., Barlow, J. F., Belcher, S. E., Britter, R. E., Cheng, H., Dobre, A., Lingard, J. J. N., Martin, D., Neophytou, M. K., Petersson, F. K., Robins, A. G., Shallcross, D. E., Smalley, R. J., Tate, J. E., Tomlin, A. S. and White, I. R. (2009) Dispersion Experiments in Central London: The 2007 DAPPLE project. Bulletin of the American Meteorological Society, 90 (7). pp. 955-970. ISSN 1520-0477

[13] GLA (2010b)http://legacy.london.gov.uk/mayor/priorities/docs/Climate_change_adaptation_080210.pdf

[14] GLA (2010a) Cleaning the Air: The Mayor's Air Quality Strategy http://www.london.gov.uk/sites/default/files/Air%20Quality%20Strategy%20v3.pdf

[15] http://uk-air.defra.gov.uk/library/no2ten/documents/110609_UK_overview_document_FINAL.pdf

[16] http://royalsociety.org/about-us/history/

his thermometer, a modified design of an Italian one, which included a scale. His thermometer was to act as a standard until 1709 with numerous developments during this period (Patterson 1951[18], Quinn and Compton 1975[19]).

New instrumentation continues to be developed and used today which allow new variables to be observed and new sites to be instrumented. Today in London Large Aperture Scintillometry (Gouvea et al. 2011[20]) and Ceilometry (Loridan et al. 2011[21]) is being used, along with multiple sensors that can now be relatively cheaply produced because of new technology (Watkins et al. 2002[22]; Mavrogianni et al. 2011[23], Ryder and Toumi, 2011[24]).

Early attention in London was also directed to the siting of instruments, again led by initiatives from the Royal Society. In the 1660s Robert Hooke made recommendations on how to observe (Kingston 1997). In 1723 there was a second attempt to establish an International meteorological network which was led by the Royal Society (Jurin 1723[25], Camuffo 2002[26]). Recommendations were made for sensor location (inside a North facing room with infrequent fire) and measurement procedures based on John Locke[27] of London (Camuffo 2002) and Robert Hooke (Kington 1997[28]).

The appropriate siting of instrumentation continues to be an issue. This is partly because instruments are deployed for multiple purposes and because of the need to ensure that instrumentation is not stolen or vandalized a particular issue in cities. Meta data about sites and instruments are critical. Robinson (2010[29]) recently

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[17] Hooke R (1665) Micrographia. http://www.gutenberg.org/ebooks/15491

[18] Patterson LD (1951) Thermometers of the Royal Society, 1663–1768, American J. of Physics 19, 523 -535

[19] Quinn TP, J P Compton (1975) The foundations of thermometry Rep. Prog. Phys. 38, 151-239

[20] Gouvea M, L Pauscher L, S Kotthaus, H Ward, F Lindberg, J Evans, C Wood, J Barlow, J Salmond, T Foken, S Grimmond (2011) Initial results from scintillometer measurements at different scales in central London, 3rd Scintillometer Workshop, Wageningen, The Netherlands, 18-19 April 2011

[21] Loridan T, CSB Grimmond, BD Offerle, DT Young, T Smith, L Jarvi, F Lindberg. Local-Scale Urban Meteorological Parameterization Scheme (LUMPS): longwave radiation parameterization & seasonality related developments Journal of Applied Meteorology & Climatology. 50: 185-202 doi: 10.1175/2010JAMC2474.1

[22] Watkins R, J Palmer, M Kolokotroni, P Littlefair (2002), The London Heat Island—surface and air temperature measurements in summer 2000, ASHRAE Trans 2002 108 (2002) (Pt1).

[23] Mavrogianni A, M Davies, M Batty, SE Belcher, SI Bohnenstengel, D Carruthers, Z Chalabi, B Croxford, C Demanuele, S Evans, R Giridharan, JN Hacker, I Hamilton, C Hogg, J Hunt, M Kolokotroni, C Martin, J Milner, I Rajapaksha, I Ridley, JP Steadman, J Stocker, P Wilkinson, Z Ye (2011) The comfort, energy and health implications of London's urban heat island Building Serv. Eng. Res. Technol. 32, 35–52

[24] Ryder CL, R Toumi (2011) An urban solar flux island: Measurements from London, Atmospheric Environment 45, 3414-3423

[25] Jurin AJ (1723) Invitatio ad Observationes Meteorologicas Communi Consilio Instituendas, Philosophical Transactions, 32, 422-427 (in Latin)

[26] Camuffo D (2002) History of the long series of daily air temperature in Padova (1725–1998) Climatic Change 53: 7–75,

[27] No reference is given by Camuffo (2002) for this. But there is a paper: Locke J (1704-1705) A Register of the Weather for the Year 1692, Kept at Oates in Essex. Philosophical Transactions, 24, 1917-1937 which has data observed by day and hour.

[28] Kington J (1997) Observing and measuring the weather: a brief history, in Hulme and Barrow (ed) 'Climate of the British Isles: present, past and future' Rouledge, London, 137-152.

[29] Robinson P. (2010) The London Meteorological Monitoring Network. MSc in EMMM, King's College London.

completed a detailed survey of a large number of the climate stations located within London. This follows an earlier study of some of the stations by Nuffield Students while at KCL[30]. These reveal marked differences between networks and sites.

The Study of London as part of studies of Regional Climate

The first sets of analyses of meteorological data observed in London were concerned not with the urban aspects of London but rather its general, regional location.

Long term rainfall records for London extend back to 1727 (Nicholas and Glasspoole 1931[31] cited by Jones et al. 1997[32]) and for temperature[33] back to 1659 (Manley 1974[34]), with daily data from 1772 (Parker et al. 1992[35]). Routine collection of temperature data in the vicinity of London appear to have begun around 1763[36] at a time when a number other cities in Europe began to collect similar observations (Brunt 1926[37]). Hourly air temperatures were collected in London at the Greenwich Observatory from 1814. Rainfall was measured from 1813 and at Camden Square from 1858 (Brunt 1926). Unfortunately, there is one gap in the data (January 1707-October 1722), which seems to stem from the fact that the data were destroyed by the Royal Society as they were perceived of being of no further use (Manley 1974, p391[38]).

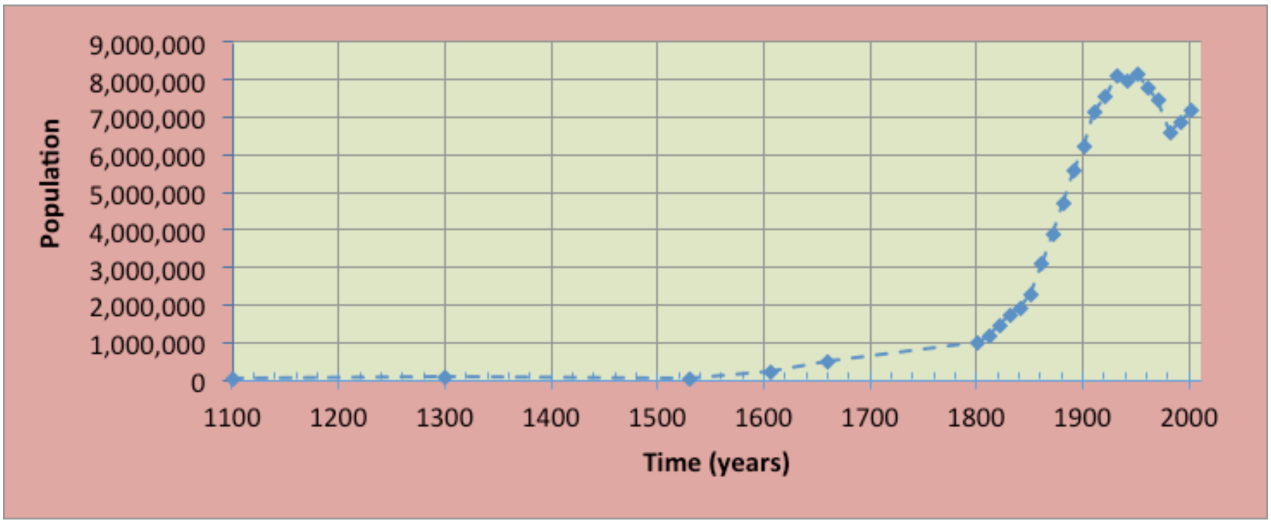

Figure 1: Population of London since 1100. Data sources: http://www.visionofbritain.org.uk/; http://www.londononline.co.uk/factfile/historical/; http://en.wikipedia.org/wiki/History_of_London

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[30] http://geography.kcl.ac.uk/micromet/

[31] Nicholas FJ and Glasspoole J (1931) General monthly rainfall over England and Wales 1727 to 1931, British Rainfall 1931,299-306.

[32] Jones PD, D Conway, K Briffa(1997) Precipitation variability and drought. in Hulme and Barrow (ed) 'Climate of the British Isles: present, past and future' Rouledge, London, 196-219.

[33] This is referred to as the Central England Temperature data set as not all data are actually for London for a variety of reasons (Manley 1974). The data are presented in a number of papers and summarized in Hulme and Barrow (1997, Appendix D)

[34] Manley G (1974), Central England temperatures: Monthly means 1659 to 1973. Quarterly Journal of the Royal Meteorological Society, 100: 389–405. doi: 10.1002/qj.49710042511

[35] Parker D E, Legg TP, Folland C . (1992), A new daily central England temperature series, 1772–1991. International Journal of Climatology, 12: 317–342. doi: 10.1002/joc.3370120402

[36] January 1764 is first monthly data reported by Brunt (1925) but he indicates there is annual data for 1763

[37] Brunt D (1926) Periodicities in European Weather Philosophical Transactions of the Royal Society of London. Series A, 225, 247-302

[38] Manley (1974) cites Philos. Trans., 24, 1707, p. 347; Symons Magazine, 59, 1924, pp. 183-184.

By 1800 London was the first megacity in the world (Molina and Molina 2004[39]) with a population of 1 million people. This grew to 1.45 million by 1821 (Figure 1). It was in this period that Luke Howard initiated his observations. These resulted in his books 'The Climate of London', editions of which were published in 1818, 1820 and 1833[40]. This seminal work, which formally recognises human effects on climates in cities, is commonly regarded as establishing the foundations of the urban climate field (Chandler 1962, Landsberg 1981, Lee 1984[41], Mills 2008[42]).

Luke Howard conducted observations of air temperature in a variety of different locations around London over a period of 25 years (Chandler 1962, Mills 2008, his Table 1). He analysed this data in conjunction with measurements established at Somerset House in 1806[43] (Chandler 1962). Although the exposure of the instrument varied between the sites, and was not always known[44] (Chandler 1962, Mills 2008), the daily data allowed him to draw conclusions that identified what we would now refer to as the 'urban canopy air temperature urban heat island (UHI)'. Luke Howard also observed other variables including rainfall, pressure, and clouds. Through careful analyses of these data, and consideration of measurement issues, he identified the controls on a number of variables. As Mills (2008) notes, Howard's interest was regional so it was the careful data collection that allowed him to identify that the observations he had were being affected by more than the regional influences. Through consideration of the impact of sites, instrumentation and exposure, he was able to conclude that London, specifically the urban emissions; e.g. anthropogenic heat (from fires, metabolism of people), urban morphology (influencing wind and radiation), and differences (in evaporation rates) influenced the observations.

Many authors since Howard have analysed data collected in London. Many, like him, have been concerned with the London data for its meso-scale features or regional location (e.g Brunt 1926). However, Bilham (1938[45]) in his book 'The Climate of the British Isles' includes an eight page section on 'Town Climates' (p303-311). Although initially concerned with air quality ('smoke pall') and the 'sordid' surroundings of the town, Bilham provides a climatology of sunshine hours comparing the centre of London with its suburbs. Recently, Ryder and Toumi (2011) had a similar focus, using low cost incoming shortwave radiation sensors located across the 33 Boroughs of London to identify what they term a 'solar flux island' which as documented by Bilham (1938, his Figure 99) shows the radiation deficit in the central area of London (Ryder and Toumi 2011, their Figure 3).

Bilham (1938) also conducted two paired comparisons of air temperature for two periods: 1906-1935 between Westminster (also known as St James's Park) and Wisley, and 1921-1935 for Kensington and Croydon, with a mean monthly analysis based on the mean, maximum and minimum temperatures. He notes that the town has higher temperatures by night and day in almost all months. The mean difference is 1°F in Kensington (1.5°F summer, 0.6°F winter). Following a detailed analysis of the relative elevation of the sites, he rejects that as the explanation, rather invoking 'retention of heat by the brickwork' and reduced nocturnal radiation loss. Recent studies

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[39] Molina MJ, LT Molina (2004) Megacities and atmospheric pollution Air & Waste Manage. Assoc. 54:644-680.

[40] Howard L (1818) The Climate of London; Howard L (1820) The Climate of London, Vol 2; Howard L (1833) The Climate of London, 2nd Edition

[41] Lee DO 1984 Urban climates Progress in Physical Geography 8: 1-31

[42] Mills G (2008) Luke Howard and The Climate of London. Weather, 63,153-157.

[43] The Royal Society moved in to Somerset House in 1780 and given the long connection already with the thermometer, the 1806 date may refer to Howard's initial measurements rather than the Royal Society's.

[44] The Royal Society was located to the East of the Strand Entrance where the Courtauld Institute of Art now occupies (http://royalsociety.org/about-us/history/somerset-house/). Some probable location could be possibly determined.

[45] Bilham EG (1938) The Climate of the British Isles, Macmillian and Co Ltd, London, 347pp

have calculated and mapped the sky view factor, which has a high correlation with the UHI (Oke 1981) for the whole of London (Lindberg and Grimmond 2010[46], Figure 2).

Bilham (1938) also analysed wind data observed at South Kensington (30’ above roof, 110’ above ground level, Science Museum), Kew Observatory and Croydon (105’ above ground level, most open). The latter was regarded as being of the outskirts of London. The role of buildings reducing wind speeds is clear from these analyses.

Three books published in 1950’s focused on regional climate (Manley 1952, Meteorological Office 1952[47], Brooks 1954[48]). Although ‘The Climatological Atlas of the British Isles’ identified 13 weather stations for London, the only maps of London are for rainfall (1881-1915, June 16 1917) and fog (visibility < 1100 yards Sept 1 1936 to March 1937 at 9h). There is also little in Brooks’ (1954) book despite three potentially relevant chapters (‘Fog and Soot’, ‘Local climate’ and ‘Where to live; Where to holiday’). Not unexpectedly, air pollution receives the most analysis with relations between coal consumption, soot deposition and visibility. Additionally, the micro-scale impact of the surface on air temperature[49] (including tarmac and brick rubble) and the influence on frost dates (but for a Midlands city) are addressed. Manley’s (1954) book ‘Climate and the British Scene’ mentions London but does not address London’s urban climate. Interestingly though, his 1944[50] paper which has a number of figures that appear in his later book, does have a section about urban climates. However, there he notes that Bilham (1938) has addressed London so Manley turns his attention to Manchester.

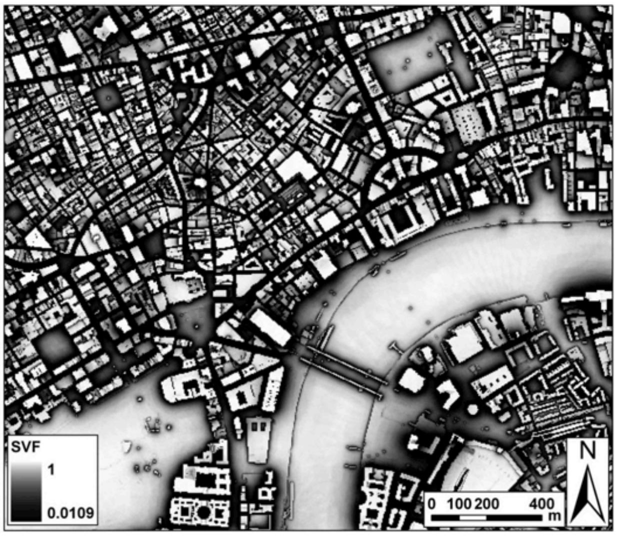

Figure 2: Sky View Factor of inner area of London (Lindberg and Grimmond, 2010). A value of 1 is an unobstructed view. St James’s Park and Somerset House are visible.

In 1976 another book with a similar title was edited by Chandler and Gregory (1976[51]) ‘The Climate of the British Isles’. This, not unsurprisingly, does have a chapter by Chandler on ‘The Climate of Towns’. Whereas later books, such as Wheeler and Mayes (1997[52]), just have a focus box on the London’s UHI (p72, Mayes 1997[53]).

The Great Smog

In terms of air pollution, little changed from the conditions that stimulated Evelyn’s (1661) writings for another 300 years. A series of “killer smog” events in the 1940s and 1950s related to exposure to sulphurous oxides (SO2 and SO4) from the

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[46] Lindberg F & CSB Grimmond, Continuous sky view factor from high resolution urban digital elevation models, Climate Research 42: 177-183 doi:10.3354/cr00882

[47] Meteorological Office (1952) The Climatological Atlas of the British Isles, M.O. 488, HMSO

[48] Brooks’ (1954) ‘The English Climate’

[49] This may have been influenced by the 1953 publication of ‘Micrometeorology’ by O.G. Sutton. This book has no reference to urban climate.

[50] Manley G (1944) Topographical features and the climate of Britain: a review of some outstanding effects. Geographical Journal,103: 241-258

[51] Chandler T, S Gregory (1976) ‘The Climate of the British Isles’.

[52] Wheeler D, J Mayes (1997) Regional Climate of the British Isles, Routledge, London, 343 pp.

[53] Mayes J 1997 South-East England, 67-88

burning of coal (Molina and Molina 2004) culminated in the “Great Smog of December 1952”. The latter resulted in the premature deaths of 12,000 (Bell et al. 2003[54]) and was sufficient to trigger public awareness of air pollution with consequent legislation (the 1956 Clean Air Act). In 1957 a smoke-free zone in central London was initiated (Chandler 1962). This stimulated a number of scientific studies and advances which have themes related to air pollution, air pollution and health/mortality, climatology and weather. Recent examples of such studies include DAPPLE9, REPARTEE[55] and CleafLO114.

The Great Smog was associated with particularly cold temperatures. As people burnt coal to heat their houses, emissions combined with those from factories, were trapped by the lower boundary layer. This impacted visibility and brought the city to a halt. Today, new instruments, many based on some form of LiDAR, allow almost real-time observations of boundary layer height. In conjunction with air quality measurements and forecast modelling, these provide the basis of systems to communicate rapidly to those who are vulnerable (e.g. Air Alert http://www.airalert.info; Air Text, http://www.airtext.info/).

Air quality remains an important issue in London today both for health reasons (e.g . Kaur et al. 2005[56], 2007[57]) and because EU Law requires directives to be met (GLA 2010, Defra 2011). As one of Europe’s Mega-cities, in a national context which is committed to more sustainable cities, and with a local government administration (Greater London Authority) that takes an active interest in climate issues and actively engages the scientific community, London provides a particularly interesting location to study urban climate and its implications for urban design.

The Urban heat island (UHI)

The first use of the term ‘heat island’ is ascribed by Landsberg (1981) to Manley (1958[58]). Manley (1958) in his discussion of the effect of the artificial warmth of London relative to snowfall patterns notes that inverse relation between ‘heat island’ strength and wind speed. He comments on the expected change in the precipitation from snow to sleet. But the term had already appeared in Balchin and Pye (1947[59]) in their study of Bath (p 303, 304). Also, in the English translation of the 2nd edition of Kratzer’s (1956) book, the city is described as being ‘like an island in a sea of cold air produced by the terrain’ (p96). As Kratzer’s book demonstrates there had been extensive research on German and Austrian urban climates in the early part of the century.

Manley’s (1958) analysis, like Bilham’s (1938), makes use of data collected at stations that were previously installed, many of them airfields. Chandler (1960, 1962, 1965[60]) provides one of the first detailed studies of the UHI of London. He (1960, 1962) identifies that although there are 17 climatological stations in London and the vicinity, which may be considered to be ‘lavish’ in

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[54] Bell ML, Davis DL, Fletcher T (2003) A Retrospective Assessment of Mortality from the London Smog Episode of 1952: The Role of Influenza and Pollution. Environ Health Perspect 112(1): doi:10.1289/ehp.6539

[55] http://nora.nerc.ac.uk/8465/REPARTEE-I and REPARTEE-II (Regent’s Park and Tower Environmental Experiment); http://www.atmos-chem-phys-discuss.net/special_issue95.html

[56] Kaur S, MJ Nieuwenhuijsen, RN Colvile (2005) Personal exposure of street canyon intersection users to
PM2.5, ultrafine particle counts and carbon monoxide in Central London, UK, Atmospheric Environment 39, 3629–3641

[57] Kaur S, MJ Nieuwenhuijsen, RN Colvile (2007). Fine particulate matter and carbon monoxide exposure concentrations in urban street transport microenvironments. Atmospheric Environment, 41, 4781-4810

[58] Manley G (1958) On the frequency of snowfall in metropolitan England. QJRMS, 84,359, 70-72

[59] Balchin WGV , N Pye (1947) A micro-climatological investigation of Bath and the surrounding district. QJRMet Soc. 73, 297-319.

[60] Chandler TJ (1965) The Climate of London Hutchinson & Co., Ltd: London.

comparison to other areas, still there was insufficient data for spatial analyses. He added 39 supplementary stations (primarily at schools) in the north east Lea Valley area of London and performed automobile traverses to understand the ‘changing intensity and form’ of the heat island. These appear to be the first mobile traverses in London (Discussion of Chandler 1962 paper), but others had previously conducted such studies elsewhere using cars and bicycles; for example in Vienna (Tollner 1932; cited by Middleton and Millar 1936), Karlsruhe (Peppler 1929a,b[61]), Munich (Budel and Wölf 1933[62]) and in Toronto (Middleton and Millar 1936).

Chandler’s (1962) specific contributions with respect to air temperature were to use fixed stations to analyse the presence and temporal characteristics of the UHI using daily and hourly records, along with mobile transects too (from Ware, north east of London along the terraces of the Lea to Canning Town or to Liverpool Street and then back to Ware). Importantly, he noted the impact of choice of the rural environment as influencing the results of urban-rural differences (he compares the implications of chosing Wisley, Swanley and Bayfordbury). He also highlighted the effect of vegetation surrounding Kensington Palace and the St James’s Park site. His explanation of the UHI focused on differences in heat capacity and conductivity of materials; presence of haze/fog (altering solar radiation receipt); mixing of air because of increased roughness of the surface; and nocturnal radiation trapping. He suggested that high thermal capacity is the most important single factor (p296).

In the discussion that followed the Chandler (1962) paper, there is evidence of plans to use the Crystal Palace tower and the Post Office tower (now known as the BT tower) for measurements. It is not clear if Chandler ever conducted measurements on the BT tower, but its use as a platform for conducting observations has been pursued more recently (e.g. Matin et al. 2011[63], Wood et al. 2010[64], Gouvea et al. 201121, Helfter et al. 2011[65]) .

Although there have been a number of other UHI studies (see other sections), Lee’s (1991[66]) study, like Chandler’s (1962, 1965), was concerned with the actual processes in the city. His interest was urban/rural differences in humidity, but he also studied the UHI, using the London Weather Centre (LWC) and Gatwick stations. Atkinson

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[61] cited by Krater 1956 Peppler, A. "Die Temperaturverha" ltnis se von Karlsruhe an heissen Sommertagen" (Temperature conditions in Karlsruhe on hot summer days), Deutsche s Meteorologisches Jahrbuch fUr Baden, 61: 59 f. 1929.

Peppler, A. "Das Auto als Hilfsmittel der meteorologischen Forschung ll (The automobile as an aid in meteorological research), Das Wetter, 46: 305-308, 1929.

[62] Budel' H. 3 and J. Wolf. "Munchener stadtklimatische Studien" (Climatic studies in the city of Munich), Das Wetter, 49: 4-10, 1933.

[63] Martin, D., Petersson, K. F., White, I. R., Henshaw, S. J., Nickless, G., Lovelock, A., Barlow, J. F., Dunbar, T., Wood, C. R. and Shallcross, D. E. (2011) Tracer concentration profiles measured in central London as part of the REPARTEE campaign. Atmospheric Chemistry and Physics, 11 (1). pp. 227-239. ISSN 1680-7316

[64] Wood CR, Lacser A, Barlow JF, Padhra A, Belcher SE, Nemitz E, Helfter C, Famulari D & Grimmond CSB (2010) Turbulent flow at 190 metres above London during 2006-2008: a climatology & the applicability of similarity theory. Boundary Layer Meteorology 137, 77-96 DOI10.1007/s10546-010-9516-x

[65] Helfter C, D Famulari, GJ Phillips, JF Barlow, CR Wood, CSB Grimmond, E Nemitz Controls of carbon dioxide concentrations & fluxes above central London [Atmos. Chem. Phys. Discuss., 10, 23739-23780, 2010 doi:10.5194/acpd-10-23739-2010] Atmos. Chem. Phys. 11, 191-1928 doi: 10.5194/acp-11-1913-2011

[66] Lee DO. 1991. Urban-rural humidity differences in London. International Journal of Climatology 11: 577–582.

(1985) cites a number of other studies of London UHI conducted by Lee in 1975[67], 1977[68], 1979[69].

Global Climate Change

Much of the research related to London's urban heat island stems from the city's long temperature record. Thus interest has also been on the urban influence as a 'contaminant' of the signal for larger scale global warming trends (e.g. Moffitt 1972[70], Lee 1992, Barrow and Hulme 1997 p37, Dukes and Eden 1997 p263). The temperature record has had numerous corrections (related to change in siting, instrumentation, discontinued data sets). These are summarized in Jones and Hulme (1997[71]). These analyses have been concerned with determining regional and global trends in temperature.

Some of the detailed analyses of the data sets have, however, been concerned with the impact of urbanization. For example, Moffitt (1972) concluded that since the 1880's urbanisation may have impacted temperature - this based on analysis of monthly data from the Kew Observatory (compared with Rothamsted) (for 1878-1968). Moffitt also identified the role of changing air quality on temperature differences. With improved air quality, winter air temperatures differences increased because of greater solar radiation receipt. The role of anthropogenic heat also was demonstrated to be important. The 1950's reduction of coal fires changed the method of building heating, as well as reduced the amount of smoke. Subsequent domestic heating has become more efficient (Moffitt 1972).

Lee's (1992[72]) study of the London's UHI, was driven by the interest in global warming data sets and the much used relation between population and UHI intensity (Oke 1973). Noting the decrease in London's population (Figure 1) he set out to determine if there had been a decrease in UHI using the stations of St James's Park and Wisely for 1962-89. Lee is careful to comment about the appropriateness of the two, with neither being ideal. He documents that daytime UHI size has decreased while night time UHI has increased in this period. From this he concludes that the population relation does not hold with decreasing population size and suggests that the reduced daytime UHI may relate to reduced anthropogenic heat emissions. However, that conclusion seems unlikely given the trends recently documented in these data (Iamarino et al. 2011[73]).

The London Climate Change Partnership (LCCP)[74] has the aim 'To ensure that London is prepared for climate change'. One action was an update of Lee's (1992) study. Wilby (2003[75]) used the same sites (St James's Park and Wisely), given the expectation that London will experience less cloud (citing Hulme et al. 2002[76]) in the future, to

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[67] Lee DO 1975 Rural atmospheric stability and the intensity of London's heat island, Weather, 30, 102-108.

[68] Lee DO 1977 Urban influence on wind direction over London,Weather, 32, 162-170.

[69] Lee DO 1979 Contrasts in warming and cooling rates at an urban and rural site, Weather, 34, 60-66.

[70] Moffitt BJ (1972) The effects of urbanization on the mean temperature at Kew Observatory. Weather, 27,12-129

[71] Jones P, M Hulme (1997) The Changing temperature of' Central England'. in Hulme and Barrow (ed) 'Climate of the British Isles: present, past and future' Routledge, London, 173-196.

[72] Lee DO 1992 Urban warming? An analysis of recent trends in London's urban heat island. Weather, 47, 50-56

[73] Iamarino M, Beevers S, CSB Grimmond (2011) High Resolution (Space, Time) Anthropogenic Heat Emissions: London 1970-2025 International Journal of Climatology DOI: 10.1002/joc.2390

[74] http://www.london.gov.uk/lccp/index.jsp

[75] Wilby RL (2003) Past and projected trends in London's urban heat island. Weather, 58, 251-260.

[76] Hulme M, Jenkins GJ, Lu X, Turnpenny JR, Mitchell TD, Jones RG, Lowe J, Murphy JM, Hassell D, Boorman P, McDonald R and Hill S (2002) Climate change scenarios for the UK: The UKCIP02 Scientific Report. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia

investigate the meteorological conditions of the most intense UHI events (defined as being > 4 °C). Using past NCEP reanalysis data he developed a multivariate statistical model, which after testing for past conditions, was used to predict future intense UHI events under different emission scenarios. Since the 1960's the intensity of the UHI has increased by 0.12°C/decade. He predicted a further 0.26°C (equivalent to +0.04°C/decade) increase by the 2080s for the mid-range emissions scenario. Wilby (2008[77]) uses his 2003 results to draw attention to the methods for analysis for future conditions using statistical downscaling to the planning community.

Jones and Lister (2009[78]) expand on Lee (1992) and Wilby (2003) by including other stations (e.g. London Weather Centre (LWC), London Heathrow (LHR) plus others) and using longer periods of records in their analyses. The rural sites of Wisley and Rothamsted are used for comparison. They note that the Wisely site is regarded to have become more sheltered with time (citing Burt and Eden 2004[79]), providing more details about the sites than has been given for some years in publications. Notably, they give the locations of the LWC station: Kingsway (1959-1965), High Holborn (1965-1992), Clerkenwell Rd (1992-2010[80]). They conclude that since 1901 the warming trends at St James's Park, Rothamstead and Wisley are statistically the same. Thus since 1901 there is not urban 'contamination' (it has not changed), so the sites can be used for global change investigations. However, the site at London Heathrow has experienced an increasing urbanizing effects from 1949 to 1980.

In 2011 Wilby et al.[81] revisit the London UHI again with respect to the change in UHI through time (1958—2010). Attention is paid to gap filling of data, length of record analysed and meteorological conditions. They conclude the need for care with analysing periods of data and identify that meteorological conditions only explains half of the summer-time night-time UHI.

UHI and Applications: Building Climate, Health, Decision Makers

Many recent studies have been interested in the UHI and its characteristics at the micro and local scale for applications. Of particular interest has been implications for building design (Watkins et al. 2002a[82],b[83], Short et al.2004[84], Kolokotronti et al. 2007[85], Mavrogianni et al. 2010[86], 2011[87]),

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[77] Wilby RL (2008) Constructing climate change scenarios of urban heat island intensity and air quality Environment and Planning B: Planning and Design, 35, 902 - 919

[78] Jones P. D. and Lister D. H. (2009) The urban heat island in Central London and urban-related warming trends in Central London since 1900. Weather, 64: 323–327. doi: 10.1002/wea.432

[79] Burt S, P Eden 2004) The August 2003 heatwave in the United Kingdom: Part 2 – The hottest sites, Weather, 59:239-242.

[80] Closed in 2010 (Wilby et al. 2011)

[81] Wilby RL, PD Jones, DH Lister (2011) Decadal variations in the nocturnal heat island of London, Weather, 66: 59-64.

[82] Watkins R, J Palmer, M Kolokotroni and P Littlefair (2002a) The London Heat Island—surface and air temperature measurements in summer 2000, ASHRAE Trans 2002 108 (Pt1).

[83] Watkins R, J. Palmer, M. Kolokotroni and P. Littlefair, The balance of the annual heating and cooling demand within the London urban heat island, BSER & T 23 (2002b) (4), pp. 207–213.

Watkins R, J Palmer, M Kolokotroni, and P Littlefair (2002a) The London Heat Island: results from summertime monitoring Building Serv Eng Res Technol 2002 23: 97-106

[84] Short, C. A. , Lomas, K. J. and Woods, A.(2004) 'Design strategy for low-energy ventilation and cooling within an urban heat island', Building Research & Information, 32: 3, 187 — 206

[85] Kolokotroni M, Y Zhang, R Watkins (2007) The London Heat Island and building cooling design Solar Energy 81 102–110

[86] Mavrogianni A, Davies M,Wilkinson P, Pathan A (2010): London Housing And Climate Change: Impact on Comfort and Health - Preliminary Results of a Summer Overheating Study Open House International, 35, 49-59

along with heat waves and health (Rooney et al. 1998[88]). These studies have been possible because of the advent of relatively low cost sensors that can be deployed across the city.

Studies of particular note, which have deployed additional sensors are BRE[89] - Building Research Establishment, and LUCID[90] - The Development of a Local Urban Climate Model and its Application to the Intelligent Design of Cities.

Other applications have resulted in numerous reports for the London Climate Change Partnership including: ‘London's changing climate - in sickness and in health’ (2011[91]), ‘Adapting to climate change: creating natural resilience’ (2009[92]), ‘Wild weather warning: a London climate impacts profile’ (2009[93]) and ‘Your Home in a Changing Climate’ (2008[94]).

Other Urban Heat Islands

McGregor et al.’s (2006[95]) report provided the material for the GLA (2006[96]) report on the UHI for decision makers. This report included UHI determined based on air temperature data but also used satellite observations from MODIS[97] of surface temperature which gives a complete spatial pattern at one instance in time. It is, however, biased by the spatial resolution of the pixels (1 km) and the surfaces in the field of view of the sensor (Voogt and Oke, 2003[98]).Measurements of the surface temperature at a number of different scales is ongoing (Kotthaus et al. 2011).

Numerical modelling of the UHI of London includes: statistical (Kolokotroni and Giridharan 2008[99], Giridharan and Kolokotroni 2009[100], with artificial neural networks; Koltoroni et al. 2010[101]);

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[87] Mavrogianni A, M Davies, M Batty, SE Belcher, SI Bohnenstengel, D Carruthers, Z Chalabi, B Croxford, C. Demanuele, S Evans, R Giridharan, JN Hacker, I Hamilton, C Hogg, J Hunt, M Kolokotroni, C Martin, J Milner, I Rajapaksha, I Ridley, JP Steadman, J Stocker, P Wilkinson, Z Ye (2011) The comfort, energy and health implications of London’s urban heat island Building Serv. Eng. Res. Technol. 32, 35–52

[88] Rooney C, McMichael AJ, Kovats RS and Coleman M 1998 Excess mortality in Englandand Wales, and in Greater London, during the1995 heatwave. J. Epidemiol. Community Health, 52,.482-486

[89] Graves H, R Watkins, P Westbury, P Littlefair (2001) Cooling buildings in London: overcoming the heat island BRE Report 431, 36 pp.

[90] http://www.lucid-project.org.uk/; ESPRC funded 2007-2010 Lead: Mike Davies (UCL)

[91] http://www.london.gov.uk/lccp/publications/londons-changing-climate-sickness-health.jsp

[92] http://www.london.gov.uk/lccp/publications/londons-changing-climate-oct09.jsp

[93] http://www.london.gov.uk/lccp/publications/wild-weather-09.jsp

[94] http://www.london.gov.uk/lccp/publications/home-feb08.jsp

[95] McGregor GR, Belcher S, Hacker J, Kovats S, Salmond J, Watkins RW, Grimmond S, Golden J, Wooster M.

2006. London’s Urban Heat Island. A report to the Greater London Authority. Centre for Environmental Assessment, Management and Policy, King’s College London, 111pp.

[96] http://static.london.gov.uk/mayor/environment/climate-change/docs/UHI_summary_report.pdf

[97] Moderate Resolution Imaging Spectroradiometer (MODIS)is on a NASA's satellite

[98] Voogt, J.A. and T.R. Oke 2003. Thermal remote sensing of urban areas. Remote Sensing of Environment 86, 370-384.

[99] Kolokotroni, M., Giridharan, R., 2008. Urban heat island intensity in London: an investigation of the impact of physical characteristics on changes in outdoor air temperature during summer. Solar Energy 82, 986–998.

[100] Giridharan R, Kolokotroni M (2009) Urban heat island characteristics in London during winter Solar Energy, 83, 1668-1682

[101] Kolokotroni M, Davies M, Croxford B, Bhuiyan, S, Mavrogianni A (2010) A validated methodology for the prediction of heating and cooling energy demand for buildings within the Urban Heat Island Case-study of London Solar Energy, 84, 2246-2255

using meso scale numerical techniques (Atkinson 2003[102], Bohnenstengel et al. 2011[103], Coceal et al. 2011); and through analysis of gobal climate model generated data (Kershaw et al. 2010[104], McCarthy et al. 2010[105]).

Role of anthropogenic heat

Repeatedly the heat generated by human activities, the anthropogenic heat, has been considered in urban climate studies. The early and current concerns about air quality are associated with anthropogenic heat releases (e.g. from burning of coal and more recently air conditioning energy demand).

Chandler (1976) suggested that the anthropogenic heat flux is ‘relatively unimportant in the urban heat budget’. But since his studies there has been increasing interest in this term for both air quality and energy impact. Based on domestic fuel consumption data, Craddock (1965[106]) calculates the impact of domestic heating to have an impact of about 0.6 °C on London’s air temperature. McGoldrick (1980[107]) provides the first spatial estimates of anthropogenic heat use. This work was expanded in the Harrison et al. (1984[108]) publication to cover the period 1971-76. More recently, in association with the LUCID project, Hamilton et al. (2009[109]) have determined the heat emission associated with buildings in London for 2005 at 1 km2 resolution. Both Allen et al. (2010[110]) and Iamarino et al. (2011[111]) address all the components of this flux (as part of MegaPoli, BRIDGE); taking transport and metabolism into account. The former is at a coarser spatial resolution (hourly temporal resolution) and the latter at a finer spatial resolution (200 m x 200 m, 30 min temporal resolution) than Hamilton et al. (2009). Iamarino et al. (2011) predict future anthropogenic heat flux under different development scenarios. Studies of this term have considered the size relative to solar radiation (Hamilton et al. 2009) and to the UHI (Kolokotroni et al. 2006[112]).

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[102] Atkinson, B.W. 2003 Numerical Modelling of Urban Heat-Island Intensity Boundary-Layer Meteorology 109: 285–310

[103] Bohnenstengel, S. I., Evans, S., Clark, P. A. and Belcher, S. A. (2011) Simulations of the London urban heat island. Quarterly Journal of the Royal Meteorological Society. (In Press)

[104] Kershaw T, M. Sanderson, D. Coley and M. Eames (2010) Estimation of the urban heat island for UK climate change projections Building Serv. Eng. Res. Technol. 31,3, 251–263

[105] McCarthy MP, MJ Best, RA Betts (2010), Climate change in cities due to global warming and urban effects, Geophys. Res. Lett., 37, L09705, doi:10.1029/2010GL042845.

[106] Craddock JM (1965) Domestic fuel consumption and winter temperatures in London. Weather 29,257-258.

[107] McGoldrick, B. (1980) Artificial heat release from Greater London 1971, Energy Workshop Report Number 20, Department of Physical Sciences, Physics Division, Sunderland Polytechnic, 32pp. (Cited by Atkinson 1985 and Scire and Hanna 1992)

[108] Harrison R, McGoldrick B, Williams CGB. 1984. Artificial heat release from Greater London, 1971-1976. Atmospheric Environment 18: 2291-2304. DOI:10.1016/0004-6981(84)90001-5.

[109] Hamilton IG, Davies M, Steadman P, Stone A, Ridley I, Evans S. 2009. The significance of the anthropogenic heat emissions of London’s buildings: A comparison against captured shortwave solar radiation. Building and Environment 44: 807-817. DOI: 10.1016/j.buildenv.2008.05.024.

[110] Allen L, F Lindberg, CSB Grimmond (2010) Global to city scale model for anthropogenic heat flux, International Journal of Climatology doi: 10.1002/joc.2210 http://onlinelibrary.wiley.com/doi/10.1002/joc.2210/pdf

[111] Iamarino M, Beevers S, CSB Grimmond (2011 in press) High Resolution (Space, Time) Anthropogenic Heat Emissions: London 1970-2025 International Journal of Climatology

[112] Kolokotroni M, I. Giannitsaris, R. Watkins (2006), The effect of the London urban heat island on building summer cooling demand and night ventilation strategies, Solar Energy, 80, 383-392, DOI: 10.1016/j.solener.2005.03.010.

Living with Environmental Change: The current nature of urban climate research

Air pollution remains an important driver to efforts to understand the urban climate of London. The current NERC funded research project Clean Air for London, ClearfLO[113], brings together researchers to integrate observations and understanding of air pollution, boundary layer meteorology and health. The need for a GLA (2010a) 'Air Quality Strategy' continues to be important as London's air quality, although much improved from the past in many respects, is the poorest in Europe[114]. The impact of not meeting EU standards is potential fines of £300 million[115] and 4300 premature deaths a year (GLA 2010a p14) in London.

Sustainability and sustainable and low carbon cities are themes that underlie current work. London is one of the cities in the EU Framework 7 project MegaPoli[116] (Megacities: Emissions, urban, regional and Global Atmospheric POLlution and climate effects, and Integrated tools for assessment and mitigation) and BRIDGE[117] (sustainaBle uRban plannIng Decision support accountinG for urban mEtabolism) and the EPSRC funded project ACTUAL[118].

Conclusions

A significant body of research has been conducted on the climate of London for a wide variety of reasons; some of the themes have not been addressed here (most notably related to precipitation – see Atkinson 1968[119], 1969[120], 1971[121], 1975[122], Tabony 1980[123]), winds (Chandler, 1965, Lee 1979), boundary layer characteristics (Rigby and Toumi 2008[124],Barlow et al. 2011[125]), CO2 characteristics (Rigby et al. 2008[126], Sparks and Toumi 2010[127], Helfter et al. 2011), air quality (e.g. Beevers and Carslaw

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[113] http://www.clearflo.ac.uk/

[114] http://www.guardian.co.uk/environment/2010/jun/25/london-air-pollution-europe

[115] http://www.guardian.co.uk/environment/2011/mar/11/britain-300m-fine-london-air-pollution

[116] http://megapoli.info/

[117] http://www.bridge-fp7.eu/

[118] http://www.actual.ac.uk/

[119] Atkinson BW 1968: A preliminary examination of the possible effect of London's urban area on the distribution of thunder rainfall. Transactions of the Institute of British Geographers 44, 97-118.

[120] Atkinson BW 1969: A further examination of the urban maximum of thunder rainfall in London, 1951-60. Transactions of the Institute of British Geographers 48, 97-117.

[121] Atkinson BW 1971: The effect of an urban area on the precipitation from a moving thunderstorm. Journal of Applied Meteorology 10, 47-55.

[122] Atkinson BW 1975: The mechanical effect of an urban area on convective precipitation. Occasional Paper No. 3, Department of Geography, Queen Mary College, University of London. (27 pp.)

[123] Tabony RC (1980) Urban effects on trends of annual and seasonal rainfall in the London area, Meteorological Magazine, 109,189-202

[124] Rigby M,R Toumi (2008) London air pollution climatology: Indirect evidence for urban boundary layer height and wind speed enhancement Atmospheric Environment, 42, 4932–4947

[125] Barlow, J. F., Dunbar, T. M., Nemitz, E. G., Wood, C. R., Gallagher, M. W., Davies, F., O'Connor, E. and Harrison, R. M. (2011) Boundary layer dynamics over London, UK, as observed using Doppler lidar during REPARTEE-II. Atmospheric Chemistry and Physics, 11 (5). pp. 2111-2125. ISSN 1680-7324

[126] Rigby M,R Toumi, R Fisher, D Lowry, EG Nisbet (2008) First continuous measurements of CO2 mixing ratio in central London using a compact diffusion probe Atmospheric Environment 42 8943–8953

[127] Sparks N, Toumi R, (2010) Remote sampling of a CO2 point source in an urban setting Atmospheric Environment, 44, 5287-5294

2005[128], Fuller and Green 2006[129], Atkinson et al. 2009[130]).

Attention has moved from careful analysis of height differences to the deployment of large number of sensors (BRE, LUCID, OPAL). The latter made possible by technological changes. Remarkably no energy balance observations have been published for London as yet, but studies of some of the individual fluxes have been undertaken; most notably radiation (Ryder and Toumi 2011; Loridan et al 2011), and anthropogenic heat flux (Harrison et al. 1984, Hamilton et al. 2010, Iamarino et al. 2011).

London is still a megacity, but clearly no longer the largest global city. Given its size and the history of measurements, it does though have a large number of climate stations. Through time a wide range of these stations have been used to characterize London's climate and the configuration of stations continues to change. The London Weather Centre closed last year, while new stations of varying exposure are being established (Robinson 2010, Ryder and Toumi 2011). There has been very little consistency in the stations used in the study of the UHI. This needs to be considered when studies are compared. Most importantly data and metadata on stations needs to be archived[131].

Through the study of the temperature in London we can see the many reasons why the climate of London been studied. From the earliest concerns about poor air quality, the first investigations of the measurement of weather variables, the first investigations of London as a location in a region, to the realization of the urban effect, to resurgence in interest in air quality again. Attention today also remains focused on many attempts to mitigate problems that have also been advocated in the past; e.g. planting trees, reducing emissions (e.g. Evelyn 1661, GLA 2010, 2011).

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Gerald Mills first brought to my attention the location of Luke Howard's urban site and through his efforts copies of Luke Howard's and Kratzer's urban climate books are now much more widely available.

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[128] Beevers SD, DC Carslaw (2005) The impact of congestion charging on vehicle emissions in London Atmospheric Environment 39, 1–5

[129] Fuller, G.W. and Green, D. 2006. Evidence for increasing primary PM10 in London. Atmospheric Environment 40, 6134 – 6145.

[130] Atkinson RW, B Barratt, B Armstrong, HR Anderson, SD Beevers, I S Mudway, D Green , RG Derwent, P Wilkinson, C Tonne, FJ Kelly (2009). The impact of the congestion charging scheme on ambient air pollution concentrations in London. Atmospheric Environment 43: 5493-5500.

[131] The thermometric data sent to the Royal Society for the period 1707-1722 appear to be have been destroyed 'as of no further use' (Manley 1974, p391)

Urban Heat Islands and sustainable urbanity: An application agenda for tropical mega-cities

Rohinton Emmanuel

Urban growth across the world remains unstoppable; more than half of the world's population already live in cities and especially in Africa and Asia, the next two decades will see a doubling of urban population over that at the start of this century. This is equivalent to the accumulated urban growth in the entire civilizational history of these continents (UNFPA, 2010). By 2030, global urban population will be nearly 70% of the total population (UN, 2010), and 80% of urban humanity will live in the developing world (UNFPA, 2007). Such rapid urban growth contributes to anthropogenic global climate change due to higher consumption of energy and materials as well as associated pollution and waste generation. Some estimates (for example, Svirejeva-Hopkins, 2004) suggest that up to 90% of all carbon emission originate in cities. Yet, the role of cities is missing in climate change model projections, as acknowledged by the Intergovernmental Panel on Climate Change (Christensen et al., 2007). Given these realities many now see cities as critical linchpin in the efforts to adapt/mitigate global climate change (Mills 2006; Grimmond, 2007; Grimmond et al., 2010). The rate of urban growth in the developing world (much of which is in the warm belt) makes the role of tropical cities in the global action to adapt to climate change even more important.

Given the demographic and social importance of warm cities, could we direct urban growth in warm places to mitigate the heat island effect and simultaneously enhance their adaptive capacity to global warming? What urban design options work best to enhance the outdoor comfort in warm humid places? How do we promote higher density urban living in the warm humid belt without compromising human wellbeing?

Evidence for urban warming in warm, humid regions

Although urbanisation is at its most intense in the warm humid belt (approx ±20o from the equator), urban climate studies from this region lag far behind those from the temperate zone. Surveying the relevant literature Roth (2007) concluded that less than 20% of all urban climate studies concern either the tropical or sub-tropical regions. A survey of the bibliographical database maintained by the International Association of Urban Climate (www.urban-climate.org) for the period of 2007-2010 showed that only 21 out 661 studies published during this period are concerned with the warm-humid region. Of these only 12 are directly relevant to the outdoor conditions in the warm-humid urban tropics.

One of the earliest UHI studies in warm, humid cities was conducted by Nieuwolt in Singapore in the mid-1960s (Nieuwolt, 1966). Since then Jauregui (Jauregui, 1993; 1996) has published two special bibliographies on tropical UHI studies. An update of key studies up to and including 2004 was provided by Emmanuel (2005).

Thermal comfort in warm, humid outdoors

The practice of applying universal thermal comfort indices to analyse the thermal conditions in the tropics continues to be the norm. Studies specifically estimating the outdoor comfort conditions in the tropics are very rare. The few that exists confirm that warm, humid dwellers typically prefer higher temperatures and have greater tolerance to warming. One of the earliest such studies was conducted in Dhakka, Bangladesh (Ahmed, 2003) (Figure 1). An outdoor temperature range of 27.5 – 32.5oC under calm conditions was considered 'acceptable' in Dhaka when the relative

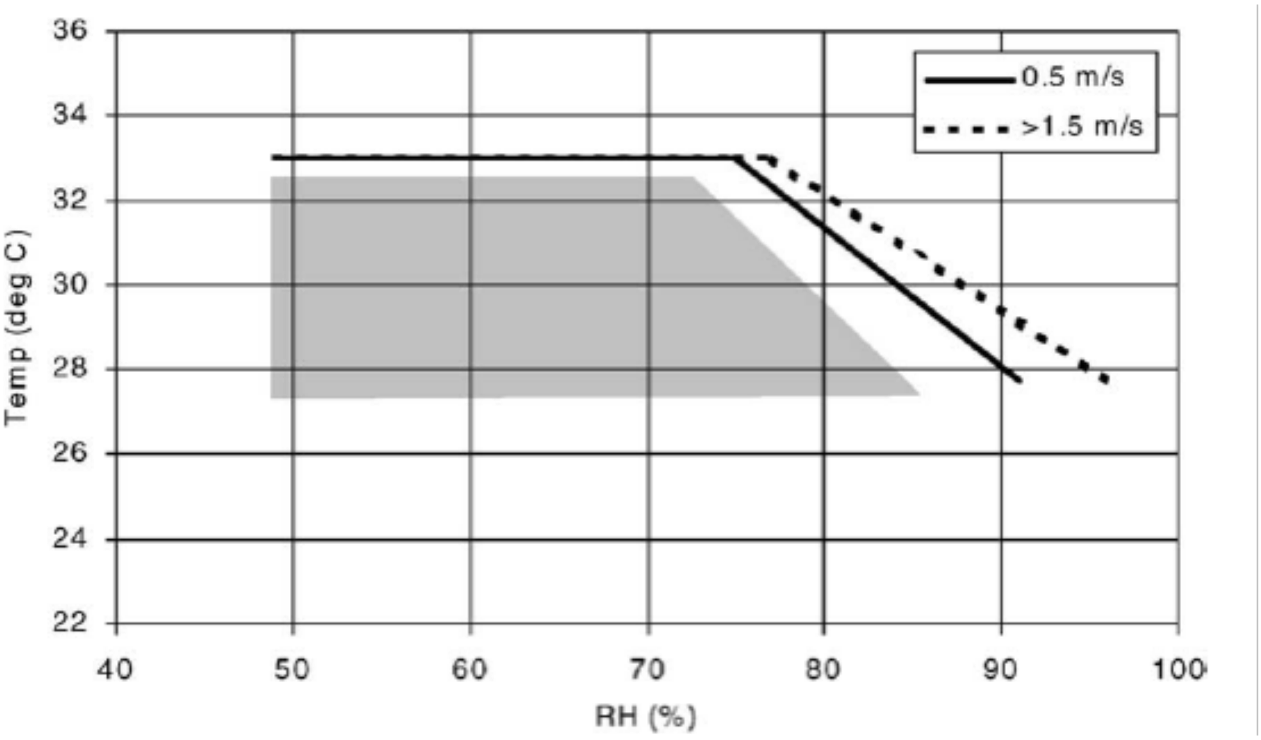

Figure 1: Outdoor comfort zone in a warm, humid city (Dhaka, Bangladesh)

humidity ranged between 70-80%. The acceptable relative humidity range can be increased by adding ventilation into the mix.

Energy and carbon implications of urban warming in warm humid areas

The relationship between UHI and key urban variables such as thermal properties, urban geometries and anthropogenic heating indicates that the energy consumption required for cooling the urban effect is likely to increase with urban growth especially during summertime and in larger urban areas in warm climates (see, Zhang et al., 2009). The need for spatial cooling energy remains suppressed in the warm humid region largely due to high energy prices and limited economic growth, coupled with relatively low urban share of the population at present. With increasing urbanisation and affluence, a warming trend (global and local) will see a massive increase in the use of air conditioning. Given the likely scale of the problem, there may not be any carbon-neutral solution (such as the meeting the energy demand with renewable technologies).

Design strategies to ameliorate urban warming in warm, humid cities

Urban design and planning strategies targeting the amelioration of urban warming in warm, humid cities are rare. It is even rarer to see an explicit link being made with urban warming strategies and the adaptation to global/regional warming in the region. Among cities with warm climates, Japanese cities lead the way in using UHI mitigation as an expressly global-warming adaptation approach (see for example, CASBEE – Heat Island, CASBEE-HI, JGBC, 2006).

An empirical evaluation of the effect of urban morphology on local climate in Beijing in summer (baseline daily mean = 24.9oC; daily maximum air temperature = 30.2oC) by Zhao et al., (2011) found that three planning indicators – building density as given by Floor Area Ratio, building height and green cover can explain nearly 99% of the local micro climate differences (surface temperature, peak temperature and time of day of occurrence of peak temperature). Given the similarities of the summer conditions in Beijing and central Japan cities to typical conditions in warm, humid climates, it is likely that the manipulation of the following three could lead to greater reduction in local warming in warm, humid cities: Shade, ventilation and green cover.

A. Shade

Evidence from the warm, humid tropics as well as from cities with warm, humid summer conditions indicate that shade (either caused by buildings or trees) to be the single most important design parameter in determining local warming/cooling as the radiative flux from direct sunlight has a strong influence on the heat balance of the body (Taylor and Guthrie, 2008). The worst street-level comfort conditions in warm, humid regions are associated with wide streets lined with low-rise buildings and no shade trees (Emmanuel and Johansson, 2006; Erell, 2008). The most comfortable conditions are associated with narrow streets and tall buildings, especially if shade trees are also present.

B. Ventilation

Ventilation has been a key strategy for thermal comfort and pollution dispersal in hot climates from ancient times. However, the low levels of wind speeds in the tropics due to the passing of the inter-tropical convergence zone twice a year makes it necessary to carefully map out the ventilation strategy at a city-wide level to induce sufficient air movement, both for pollution dispersion as well as thermal comfort. It will also enhance the cooling potential of naturally ventilated buildings (which is the commonest approach to indoor cooling in the warm, humid tropics). Hong Kong's approach to a city-wide ventilation strategy via the 'Air Ventilation Assessment' (AVA) method (Ng, 2009) best exemplifies such a planning assessment method.

Another strategy to induce street-level ventilation is to use the differences in surface temperatures of vertical surfaces of buildings in high density areas (see, Yang and Li, 2009).

C. Urban greenery

The importance of urban greenery to human comfort at street level is long recognised. However efforts to use greenery to ameliorate urban warming need to be cognizant of the scale of the effect due to different kinds of greenery, limitations of its use and the unintended consequences that might arise by their haphazard deployment.

Perhaps a meta-review conducted by Bowler et al., (2010) on the purported effect of urban greenery best sums up the findings to-date. Noting the nature of observational studies on urban green effect (small numbers of green sites), Bowler et al., (2010) concluded that 'the impact of specific greening interventions on the wider urban area, and whether the effects are due to greening alone, has yet to be demonstrated.' Further empirical research is necessary in order to efficiently guide the design and planning of urban green space, and specifically to investigate the importance of the abundance, distribution and type of greening. It is also necessary to be mindful of the interference urban greenery could cause to street-level pollution removal, especially on the leeward side of urban canyons (Gromke et al., 2008; Salim et al., 2011) as well as the enhanced water use that might be required to maintain the green cover (Gober et al., 2010).

D. Albedo

In the typically low wind speeds prevalent in tropical cities, the effect of facade materials and their colours assume greater significance. Priyadarshani et al., (2008) found that low albedo facade materials in Singapore led to a temperature increase of up to 2.5oC at the middle of a narrow canyon. Emmanuel and Fernando (2007) found that high albedo could make sunlit urban street canyons up to 1.2oC cooler in Colombo, Sri Lanka.

However, it is important to keep in mind that albedo enhancement strategies, like urban greening, are more likely to show improvements in air temperatures than thermal comfort (Emmanuel et al., 2007). From an urban design point of view, mitigation options ought to focus on thermal comfort enhancement (including the MRT) rather than merely attempting to control air temperatures (Emmanuel and Fernando, 2007).

A more promising approach to cool the many dark surfaces in cities that cannot be effectively shaded is the use of the so-called cool materials (either low albedo or phase change materials – PCMs). Synnefa et al., (2011) showed that PCMs can effectively reduce surface temperatures of dark asphalt surfaces in cities (typically these are 'hard-to-treat'). The added advantage of PCMs is that they are available in many colours, thus eliminating the need for white surfaces (with their attendant maintenance problems in humid environments). These strategies could not only reduce building energy consumption but could also lead to citywide lowering of ambient air temperatures, slowing ozone formation and increasing human comfort.

Design implications

A recent simulation exercise using the SHIM Model and ENV-met simulations (Emmanuel et al., 2011) of the likely urban warming effects of the planned urban growth trajectories in the warm, humid city of Colombo, Sri Lanka indicates that there are significant differences in the likely warming rates between different urban growth trajectories. A moderate increase in built cover appears to lead to the least amount of warming. At the neighbourhood scale streets oriented to the prevailing wind directions with staggered building arrangements together with street trees appear to offer the best mitigatory possibility to deal with urban warming in warm humid cities. A combined approach of all of the above could in theory, eliminate the warming effect due to the heat island phenomenon.

Urbanisation has consequences not only on local warming but also on regional and perhaps global warming. The rapid development of tropical megacities poses a special problem in terms of managing such local warming from reaching the regional/global scale. However they also present an opportunity in that the increasing urban growth and associated infrastructure development could be used as a first line of defence against the vagaries of climate change. Such action remains within the urban planning and design domain and the phenomenon of UHI provides both a focal point as well as a political/policy opportunity to cities to contribute to the issue of adaptation to climate change. As Oke (1997) pointed out the scale of climate modifications that have occurred in urban areas is of similar rate and magnitude to the climate change expected over this century due to increasing greenhouse gases. Given our results (of likely cooling from a judicious use of shading, ventilation and urban greenery), it is possible to learn planning lessons that could potentially eliminate the likely global warming effects expected in warm, humid cities. Furthermore, UHI mitigation provides an opportunity to 'localise' climate change action since it is technically legitimate (as we have shown above) while also being politically more accountable (see, Corburn, 2009).

Given the links between sprawling cities and urban warming (see, Stone et al., 2010), our own work in the tropics show that highly compact neighbourhoods with carefully designed densities and greenery to shade and ventilate streets may offer an important tool for adapting to the heat-related health effects associated with ongoing and future climate change.

Mills (2006) suggested that for urban climate knowledge to be better utilised in sustainable urban design (and by extension, cites adapted to climate change), the following must be met:

1. The needs of designer (e.g. existing built forms and individual building needs),
2. A range of outdoor urban spaces,
3. The links between indoor and outdoor air,
4. Outdoor levels of comfort,
5. Case-studies that link design decision to measurable impacts and,

The utilisation of urban climate knowledge for better city planning needs action from the research community, planners and decision makers and other stakeholders:

<u>From the urban climate research community:</u>

Make a stronger case linking the building 'in' to the urban 'out'
Treat outdoor comfort as a quality-of-life issue
Reflect the needs of designer (e.g. existing built forms and individual building needs)
Develop strategies for a range of outdoor urban spaces
Create database of 'case studies' that link design decision to measurable impacts (need measurement & analysis protocols)

<u>From the decision makers:</u>

Political champions for heat island mitigation in the tropics

Patience, prudence and institutional mechanisms to be ‘in it’ for the long haul
Identify early win-wins
View UHI mitigation as a global climate change adaptation mechanism

<u>Other stakeholders:</u>

Increased awareness of the changed climate context
Urban climate well being as a common good
Willingness-to-pay

Concerted action to help cities tackle local warming can showcase the possibilities of local action to tackle local warming. Such cities can then be used as test beds for assessing the impacts of, and adaptation strategies to, climate change on both local and global scales.

REFERENCES

Ahmed KS. 2003. Comfort in urban spaces: defining the boundaries of outdoor thermal comfort for the tropical urban environments, Ener. Build. 35, pp. 103-110Bowler et al., (2010

Christensen JH. et al. 2007. Regional climate projections, in Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by S. Solomon et al., pp. 847–940, Cambridge Univ. Press, Cambridge, U. K.

Corburn J. 2009. Cities, climate change and urban heat island mitigation: localising global environmental science. Urban Studies, 46, pp. 413–427

Emmanuel R. 2005. An Urban Approach to Climate Sneistive Design: Strategies for the Tropics. London: E & FN Spon Press

Emmanuel R. Perera NGR, Maduwanthi H. 2011. Mitigating urban warming as an adaptation strategy to climate change in the warm, humid tropics. Build. Env. (in review)

Emmanuel R, Fernando HJS. 2007. Urban heat islands in humid and arid climates: role of urban form and thermal properties in Colombo, Sri Lanka and Phoenix, USA. Clim Res. 34, pp. 241–251

Emmanuel R, Johansson EJ, Rosenlund H. 2007. Urban shading – a design option for the tropics? A study in Colombo, Sri Lanka. Int. J. Climatol. 27, pp. 1995–2004

Emmanuel R, Johansson EJ. 2006. Influence of urban morphology and sea breeze on hot humid microclimate: the case of Colombo, Sri Lanka. Clim. Res. 30, pp. 189–200

Erell E. 2008. The application of urban climate research in the design of cities. Advances in Building Energy Research, 2, pp. 95-121

Gober P, Brazel A, Quay R, Myint S, Grossman-Clarke S, Miller A, Rossi S. 2010. Using watered landscapes to manipulate urban heat island effects: how much water will it take to cool Phoenix? J. Am. Plan. Assoc. 76, pp. 109–121Grimmond et al., 2010

Grimmond CSB, Roth M, Oke TR, Au YC, Best M, Betts R, Carmichael G, Cleugh H, Dabberdt W, Emmanuel R, Freitas E, Fortuniak K, Hanna S, Klein P, Kalkstein LS, Liu CH, Nickson A, Pearlmutter D, Sailor D, Voogt J. 2010. Climate and more sustainable cities: climate information for improved planning and management of cities (Producers/Capabilities Perspective). Procedia Environmental Sciences, 1, 247–274

Grimmond S. 2007. Urbanization and global environmental change: local effects of urban warming. Geographical Journal, 173, pp. 83-88

Gromke C, Buccolieri R, Di Sabatino S, Ruck B. 2008. Dispersion study in a street canyon with tree planting by means of wind tunnel and numerical investigations – evaluation of CFD data with experimental data. Atmos. Env. 42, pp. 8640–8650

Japan Green Build Council (JaGBC) and Japan Sustainable Building Consortium (JSBC).2006. CASBEE for heat island (CASBEE-HI). Japan: JaGBC and JSBC (Availablefrom: http://www.ibec.or.jp/CASBEE/index.htm, accessed 12 May 2011)/; 2006.

Jauregui E. 1993. Bibliography of Urban Climate in Tropical/ Subtropical Areas, 1981–1991, WCASP-25, WMO/TD-No. 552. World Meteorological Organisation: Geneva; 87

Jauregui E. 1996. Bibliography of Urban Climatology for the Period 1992–1995 Including a Special Section on Urban Climate in Tropical/ Subtropical Areas, WCASP-36, WMO/TD-No. 759. World Meteorological Organisation: Geneva

Mills G. 2006. Progress towards sustainable settlements: a role for urban climatology. Theoretical and Applied Climatology, 84, pp. 69–76

Ng E. 2009. Policies and technical guidelines for urban planning of high-density cities – air ventilation assessment (AVA) of Hong Kong. Build. Environ. 44, pp. 1478–1488

Nieuwolt S. 1966. The urban microclimate of Singapore. J. Trop. Geog. 22, pp. 30-37

Oke TR. 1997. Urban climates and global change. In, Perry A and Thompson R (eds). Applied Climatology: Principles and Practices, pp. 273–287. London: Routledge

Priyadarsini R, Wong NH, Cheong KWD. 2008. Microclimatic modelling of the urban thermal environment of Singapore to mitigate urban heat island. Solar Energy. 82, pp. 727–745

Roth M. 2007. Review of urban climate research in (sub)tropical regions, Int. J. Climatol. 27, pp. 1859–1873

Salim SM, Cheah SC, Chan A. 2011. Numerical simulation of dispersion in urban street canyons with avenue-like tree plantings: Comparison between RANS and LES. Build. Env. 46, pp. 1735–1 746

Stone B, Hess JJ, Frumkin H. 2010. Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities? Env. Health Pers. 118, pp. 1425 – 1428

Svirejeva-Hopkins A, Schellnhuber HJ, Pomaz VL. 2004. Urbanised territories as a specific component of the global carbon cycle. Ecological Modelling, 173, pp. 295–312

Synnefa A, Karlessi T, Gaitani N, Santamouris M, Assimakopoulos DN, Papakatsikas C. Experimental testing of cool colored thin layer asphalt and estimation of its potential to improve the urban microclimate. Build. Env. 46, pp. 38–44

Taylor B, Guthrie P. 2008. The first line of defence: Passive design at an urban scale. Proceedings of Conference: Air Conditioning and the Low Carbon Cooling Challenge, Cumberland Lodge, Windsor, UK, 27-29 July 2008. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk (accessed 15 Feb 2010)

United Nations, Department of Economic and Social Affairs, Population Division (2010). World Urbanization Prospects: The 2009 Revision. CD-ROM Edition – Data in digital form (POP/ DB/WUP/ Rev.2009)

Yang L, Li Y. 2009. City ventilation of Hong Kong at no-wind conditions. Atmos. Env. 43, pp. 3111–3121

Zhang P, Imhoff ML, Wolfe RE, Bounoua L. 2009. Characterizing urban heat island effect at global settlements using MODIS and nightlight products. Paper presented at the American Geophysical Union, Fall Meeting 2009, abstract #U33B-0054 (can be accessed at: http://adsabs.harvard.edu/abs/2009AGUFM.U33B0054Z, last accessed 11 April 2011)

Zhao C, Fu G, Liu X, Fu F. 2011. Urban planning indicators, morphology and climate indicators: A case study for a north-south transect of Beijing, China. Build. Env. 46, pp. 1174–1183

Improvement of the thermal comfort within dense housing complexes

Sascha Henninger

Introduction

In the last decades the subject of environment and climate protection within urban areas attains more and more priority. Not least because of the negative effects of urban climate modifications on the sense of human well-being. People are increasingly sensitized by the global warming and the impacts of weather caprioles. Meanwhile the acute need for action at the urban scale is recognized. The improvement of the urban climate involves a vast potential regarding future environment protection arrangements. Urban planning appropriate for climatic modifications tries to meet these impacts of the urban climate. A narrow dovetailing of the applied urban climatology, which deals with the analysis of local climate and the urban air pollution situation, enables the planners an adequate urban planning with climate and air pollution maps; based on these the application of climate and air pollution maps on physical planning helps to react on problematic issues. According to the geographic location and the size of the examined urban area, related to the behavioural patterns of their inhabitants, it results into different planning assignments. The realization of extensive local climatic investigations is extremely important, as well as an interdisciplinary cooperation with the traffic planning and the urban green space planning office. This context should be investigated within large urban agglomerations of Asian countries, because increasing urbanization and environmental problems become a challenge for big cities like e. g. the South-Korean metropolitan city of Daegu (35° 73` N; 128° 34` E; ~ 2.5 million inhabitants; A = 885.62 km^2). The aim of this initial project was to analyze how the potential negative modifications of the urban climate influence the actual structure of housing of the South-Korean city to confirm the thermal comfort and its consequences for human health.

Investigation area

The climatic conditions of the metropolitan area are characterized by intensive heat waves (> 40°C) during the summer months, heavy rainfall events as well as a warm and humid monsoon. Additionally, this local climatic situation is intensified by the location of the urban area within a basin-shaped valley, accompanied by an extremely reduced air exchange. An initial harbinger of this climatological development and the ongoing deterioration of the thermal situation within the urban area are chronic diseases and tiredness (Kim et. al, 2004).

Urban planning in South-Korea means less measures for redevelopment or renovating. Traditional and on many occasions neglected detached family houses have to subside dense and oversized massive constructions. One of the main challenges for South-Korean planners is to make new housing estates available (Son et. al., 2008). That`s why this microclimatic analysis should not create new housing estates, but guarantee the same living space and simultaneously optimizing the residential environment from the climatological point of view, to solve the problem of negative thermal behaviour within these corresponding areas.

The investigation area of “Sincheon-View“ consists of 13 high-rising housing complexes with 15 till 18 floors. The buildings are faced lateral to the ventilation path or the river respectively. So the cold air flow from the south is restricted on its way to the city centre. Instead the cold air masses are dammed at the southern edge of the residential area, with the result that this is also only slightly ventilated and accordingly cannot participate the cool air, too.

Not only projects of urban greening, but also the nocturnal influence of cold air flow was paid attention to. For these purposes the investigation area offered an outstanding ventilation path, the so-called “Sincheon River”. Its source is in the southern mountain area and the river flows along the urban area, especially through main parts of the city centre. Unfortunately, due to the aim of having stylish residential complexes with a river view, more or less all multiple housing complexes along the bank are faced south parallel to the flow direction.

The investigation area “Sincheon-View“ was analyzed due to its microclimatic situation by the simulation model ENVI-met 3.1. Thereupon it was possible to determine the different types of surfaces, the diverse structure of housing and the changing vegetation in a three-dimensional way and also in mutual dependence of the local climate (Bruse, 2003).

Results

The microclimatic modelling of the actual state of the investigation area verified the climatological in-situ measurements. Areas of conflict regarding the cold air flow and the ventilation within “Sincheon View“ could be identified. Against the setting of the thermal strain within this area air temperature was the main coefficient to look for. So in-situ measurements as well as the results of ENVI-met offered a temperature difference between the residential area and its surroundings of 2.5 K within and to the nearby vicinity of “Sincheon View“ (fig. 1). Also wind speed decreases from a mean of 2.3 m s-1 along the river and outside of “Sincheon View“, whereas from the exteriors to the inner part of the investigation area wind speed decreases from 1.2 to 0 m s-1. Even the vegetation stock within the investigation area has a negative influence on the ventilation. According to a leaf area of approx. 1 m2 m-3 windspeed is additionally plainly reduced by about 0.8 m s-1.

Three alternatives were offered to the South-Korean planners to have an overview how the housing complexes could be modified from the view of urban climatology. The aim of these was to show, that the thermal comfort of an urban area could not only be improved by creating a higher vegetation stock.

The first alternative (fig. 2) based on the actual structure of housing, but with less sealed areas and a higher rate of trees and bushes and leaf area density respectively, which promises more shading, at the first sight. However, it could be shown, that due to this additional greening there was furthermore a decline of air exchange of the total investigation area. Especially areas which actually still participate of higher wind speed and a better exchange lose this advantage. Though shading indicates a positive thermal effect on the one hand, but the new potential vegetation stock interferes this effect permanently due to a decreasing air exchange on the other hand (fig. 2).

So, additionally, two alternative constructions were recognised. The aim of both was enhancing the air circulation to ensure a better ventilation with the nearby vicinity, especially with the “Sincheon

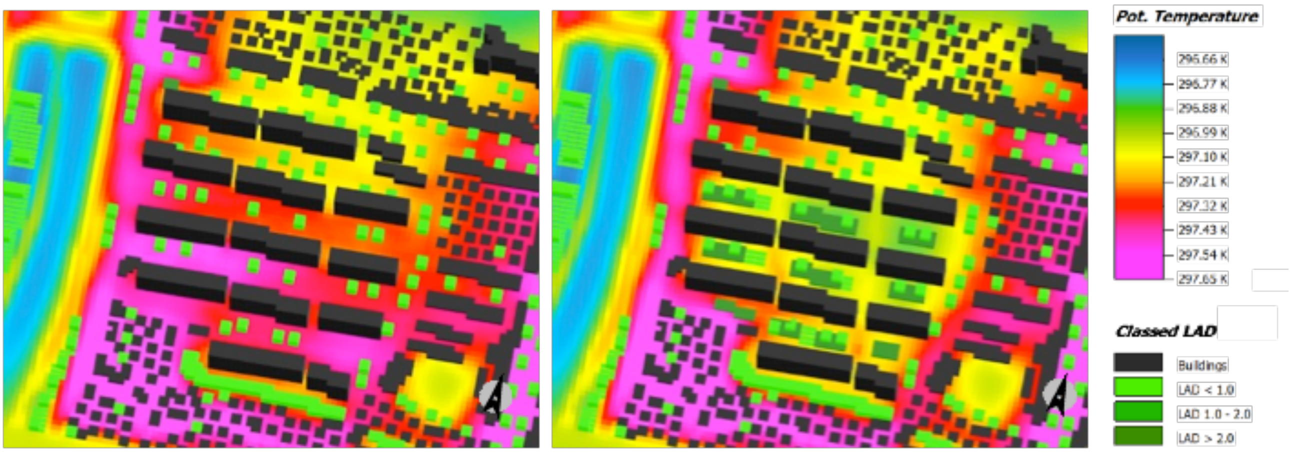

Figure 1 & 2: Actual thermal situation within the residential area “Sincheon View“ (fig. 1; left) and the thermal situation of the actual housing structure with additional greening (fig. 2; right)

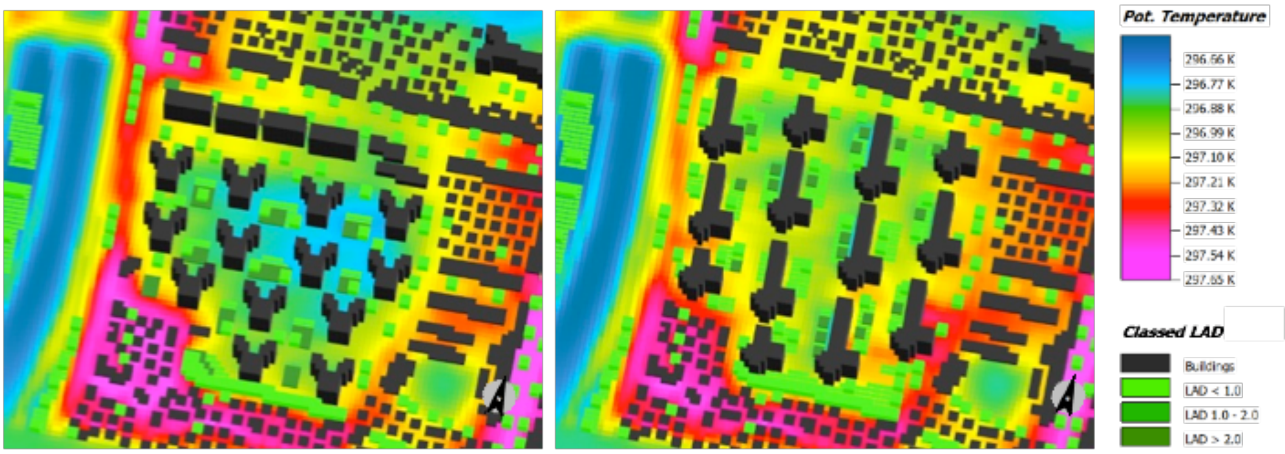

Figure 3 & 4: Thermal situation within the residential area “Sincheon View“: Alternative one with dot-shaped tower buildings and additional greening (fig. 3; left) and alternative two with ribbon development and additional greening (fig. 4; right)

River“. Alternative one (fig. 3) was a dot-shaped arrangement of tower buildings, the second one (fig. 4) was a ribbon development, adapted to the main wind direction. Both had in common, that there were less sealed areas and slightly more vegetation in some parts of the residential area. The first alternative offered 13 tower buildings with 18 floors by four living quarters per floor; six living quarters more in comparison to the actual housing situation, but with less developable area. The second alternative was optimized by taking the wind specific situation of this area into account. Sensitive parts were kept free from vegetation, with more lawn areas instead of bushes and trees. All in all 22 single buildings with 18 floors, in comparison to the actual situation these are eight additional living quarters.

Finally, we could reveal that there would be a better air exchange between the residential complex and its nearby vicinity. Especially the nocturnal cold air flow is not blocked anymore and can consequently spread within the investigation area. So the two alternative constructions indicate that an additional vegetation, an optimized ventilation and, in dependence of the time of the day, the shading of the buildings can achieve an improved thermal comfort for the people by decreasing the temperature of about 3 K. According to the dot-shaped development, which offers the slightest resistor, wind speed increased up to 1 m s-1 (fig. 3). In comparison to the actual situation this is an increase from 0.2 to 0.6 m s-1. Most notably at noon the improved ventilation leads to a positive thermal situation not least for people`s comfort.

Conclusion

Different planning, construction forms and the composition of open spaces can have diverse effects on the local climate within an urban area. For urban planning this means either to mitigate or avoid adverse factors, but still be anxious that otherwise positive qualities could get lost. So there is an important role for the applied urban climatology, which is able to reproach conceptions of implementation for urban planning processes.

The arrangement of buildings and the ground cover within housing complexes are considerable variables for the process of air exchange and a good thermal comfort. Fresh and cold air could be led into such residential areas, where these achieve a decrease of the local hyperthermia. Due to the analysis of the investigation area “Sincheon-View“, it can exemplarily show, that councils and planners have to accomplish areas with a climatological as well as ecological importance (ventilation paths, production of cold air and urban green spaces) in an adequate shape or to keep these clear for coming plans and measures relevant for the local planning. By integrating competent scientific knowledge urban areas have the opportunity of a more structured future planning, getting a better quality for living and a sustainable environmental design.

REFERENCES

Bruse, M. (2003): Stadtgrün und Stadtklima. Wie sich Grünflächen auf das Mikroklima in Städten auswirken. Stadtklima , LÖBF-Mitteilungen 1/03, 66-70. (in German)

Kim, H.-D., Koo, H.-S., Kang, S.-D. (2004): Numerical simulation experiment on the wind ventilation lane of the local circulation winds in Daegu. Journal of the Environmental Sciences, 13/ 4 , 367-376.

Son, K.-S., Jung, E.-H., Kim, D.-W., Ryu, J.-W., Cha, J.-G. (2008): A Study on Planning Methods of Apartment Complex for a Sustainable Residential Environment. Proceedings of World Academy of Science, Engineering and Technology, 36, 715-718.

The use of urban vegetation as a tool for heat stress mitigation in hot and arid regions, case study: Beer Sheva, Israel

Oded Potchter, Yaron Yaakov, Limor Shashua-Bar, Shabtai Cohen, Josef Tanny and Pua Bar-Kutiel

1. Introduction

One of the most important implications of the Urban Heat Island (UHI) is the increase of heat stress during the day in the summer, which aggravates the thermal discomfort of human beings (Givoni, 2005; Emmanuel et al, 2007). The use of urban greenery for sustainable passive cooling in urban planning to mitigate heat island intensity is becoming important for energy savings and improved human comfort (Steemers, 2003; Grimmond, 2007). Numerous studies have investigated the impact of parks and street trees on temperature reduction in the urban environment at pedestrian level and found that the reduction can reach 2°-4°C (Dimudi and Nikapoulodo 2003: Shashua-Bar et al. 2010; Tsiros, 2010); at some sites in extreme climatic conditions the cooling effect may reach up to 5-8°C (Miller et al, 2006). The vegetation cooling effect is particularly important in hot, arid climates due to its impact on heat stress reduction. However, some researchers have pointed out that sometimes urban green areas can be warmer than the surrounding built-up area and hence cause uncomfortable micro-climatic conditions (Grimmond, 1996; Jauregui, 1997; Potchter et al., 2006).

Due to the limited number of studies on the urban heat island of desert cities it is still difficult to characterize the urban climate of desert cities. Nevertheless, studies in desert cities such as Arizona, USA (Balling and Brazel, 1986; Baker et al, 1992), Eilat, Israel (Sofer and Potchter, 2006) and Khartoum, Soudan (Elagibfy , 2010), showed that UHI intensity can be higher in summer than in winter and has increased over time due to rapid urban growth. Studies in other desert cities such as Cairo (Robaa, 2004), have clearly identified an UHI during the summer too.

Pervious studies focused on the impact of urban vegetation on human comfort and found that the impact at pedestrian level micro-climate is more pronounced than the cooling effect itself due to the effect of the trees on Mean Radian Temperature, which is related to the tree shading effect (Mayer and Matazrkis, 2006: Ali-Toudert and Mayer 2007:). However, it seems that there is a dearth of studies that quantify the impact of urban vegetation on the thermal comfort of people using thermal physiologically significant indices (Mayer and Matzarakis, 2006). Therefore the objective of these studies is to expand knowledge on methods to reduce thermal stress below the tree canopy in hot summer conditions.

The aim of this research was to examine the impact of vegetation on two urban issues; urban parks and street trees, on the micro-climatic conditions in the city of Beer-Sheva and their impact on heat stress mitigation as a case study of desert cities.

2. The Characteristics of the Beer Sheva Climate and its UHI

The study site is the desert city of Beer-Sheva located in a hot, arid climate (204 mm), characterized, during the summer, by high values of solar radiation, high temperatures (32.7°C) and low relative humidity values (33-38%) during the day, high diurnal and seasonal temperature fluctuation. All of these are predisposed to create uncomfortable conditions for humans.

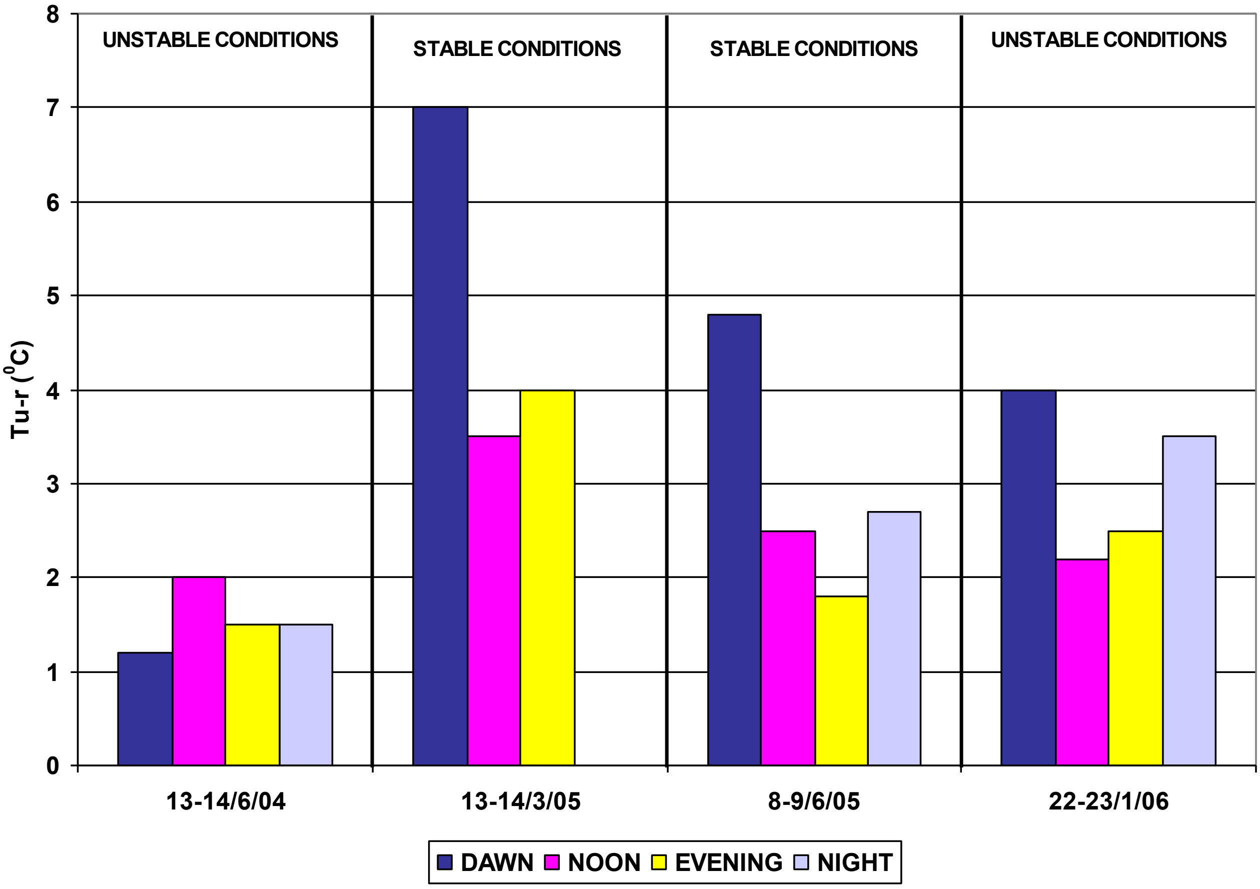

Figure 1: UHI intensity as measured during selected case studies

The population of the city of Beer Sheva has grown rapidly from 45,000 inhabitants in the year 1965 to 210,000 inhabitants in the year in 2010 and as a result its UHI has increased over time. Previous studies of the Beer Sheva climate showed rapid increases in its UHI. In the winter of 1965 the UHI intensity was 30C, in winter 1979, 50C and in 2006 the UHI reached 70c in the winter and 40C in summer (Potchter et al, 2006). Figure 1 demonstrates the UHI intensity as measured during selected case studies in the last four years. It appears that the intensity of the Beer Sheva Urban Heat Island, in terms of population size, is higher than most of the desert cities that have so far been investigated.

An examination of long term trends in Beer Sheva, show that from the 60s the average temperature at 15:00 hours has risen by 0.50C per decade. These air temperature increases have had a negative impact on human comfort by aggravating the duration and intensity of heat stress (Ben Shalom and Potchter, 2009).

3. The Mitigation of the UHI and Heat Stress Using Urban Greenery in a Desert City

The impact of urban vegetation on the micro-climatic conditions in the city of Beer-Sheva was examined in two urban tissues: (a) streets lined with trees and (b) urban parks.

The methodology of the study included two stages: The first stage included empirical meteorological measurements (radiative fluxes, air temperature, air humidity, wind speed and direction). The second stage was the calculation of PET using the PC modelling program, RayMan (Matzarakis et al., 2007) developed according to Guideline 3787 of the German Engineering Society (VDI, 1998) which calculates the radiative fluxes in simple and complex environments on the basis of various parameters, such as air temperature, air humidity, degree of cloud cover, time of day and year, and the albedo of the surrounding surfaces, elevation and location. According to the model, the calculation of thermal sensation requires the input of the following constants: body surface area

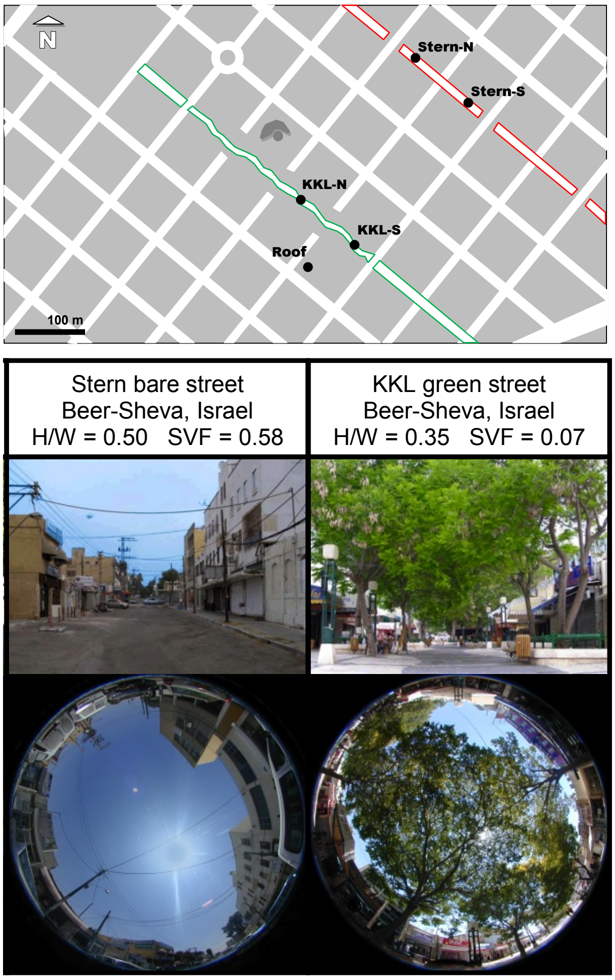

Figure 2: The urban tissue of the study site (top) and the Characteristics of the investigated streets. (bottom)

was standardized to 1.9 m2, which represents a human with a height of 1.75m and a bodyweight of 75 kg (Hoppe, 1984); the metabolic rate (Met) was fixed at an average value of 80 W/m2 for a standing person; the insulation factor of clothing (Icl) was standardized to 0.9 for light summer clothing (Jendritzky et al., 1990).

The effect of street trees: In order to examine the effect of street trees on climatic variables and human comfort two NW-SE oriented parallel streets were chosen: a street with mature Jacaranda trees predominating, and a bare street with no trees. Both streets were of the same width of 15 m and surrounding buildings were of similar heights (1 to 2 stories) (Figure 2). In situ measurements were taken in 2009 during two periods: the beginning of summer (June) and the end of summer (September).

Figure 3 shows climatic data for the measurement days in June and in September. Maximum air temperature reached up to 35˚C in the bare street while on the street with trees, temperatures were lower at 32.2˚C. As shown in Table 3, apart from the temperature, minor differences were recorded in the water vapour pressure; also, wind velocity was reduced in the green street as compared to the bare street, presumably due to the larger air flow resistance created by the trees. The results in September show a similar trend but at lower temperature values than in June, reaching up to 33˚C for the bare street and 31.7˚C for the green street.

Calculation of the PET index showed that although the cooling effect of street trees is around 1.5-3.0°C, the reduction of PET is much more pronounced; 12°C at midday and at certain hours it can reach even 18°C.

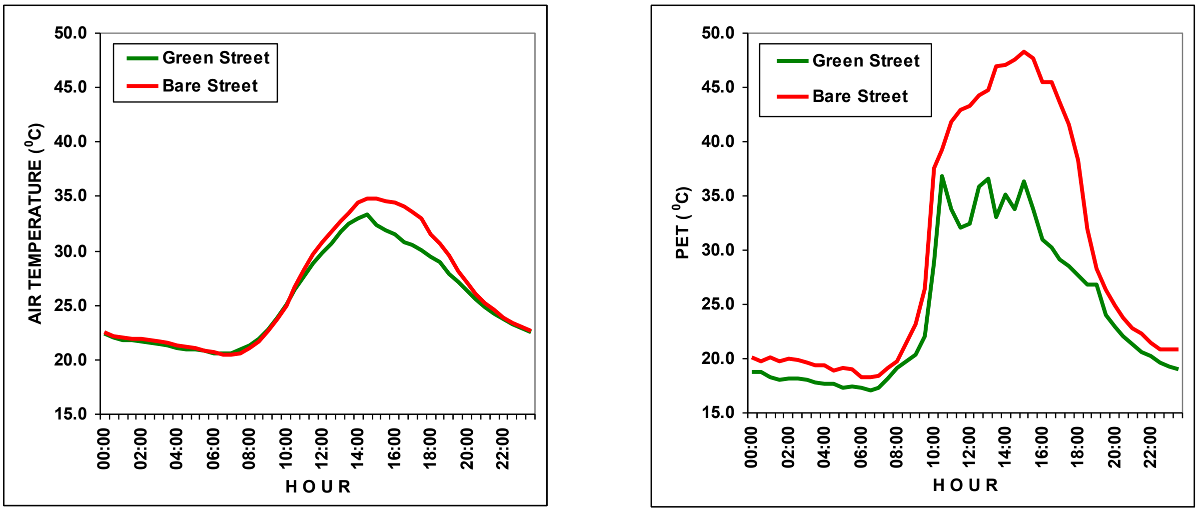

Figure 3: A comparison of average hourly temperature (left) and PET calculations (right) between the street with trees (Green Street) and a bare street canyon 7-11 June 2009

The effect of trees and grass on urban climate and heat stress mitigation: In order to examine the effect of various vegetation types on heat mitigation, an urban park, located at the center of the city was chosen as a study unit. The park size is 80,000 square meters, containing a small group of mature Tamarix trees, a small group of mature Prosopis trees and a large lawn between them. Intensive meteorological measurements were carried out for a week in June 2010.

Table 1: Climatic data for the fixed stations at the case study locations. Averages for June 7-11 and September 6-10, 2009 Beer Sheva, Israel

Climatic variable	June 7-11 2009		September 6-10 2009	
	Green Street	Bare Street	Green Street	Bare Street
Max air temp. T_a (°C)	32.0	35.0	31.7	33.1
Min air temp. T_a (°C)	20.7	20.8	20.5	20.4
Max water vapour pressure VP (hPa)	26.5	27.5	24.7	25.6
Min water vapour pressure VP (hPa)	19.6	20.8	19.6	19.8
Max wind speed (m s^{-1})	0.3	0.8	0.4	0.8
Max avg. PET (°C)	36*	48	36*	46
Max avg. Tmrt (°C)	45*	68	40*	63

Table 2 and Figure 5 show climatic data of the measurement days in the urban park in Beer Sheva in June 2010. The hottest temperatures were measured in the urban area, the grass was found to be slight cooler than the built area and the Tamarix trees were found to be up to 3°C cooler than the built area. Although the lawn and trees were cooler than the built environment, the lawn was found to create uncomfortable human thermal sensation during the day and night mainly due to the lack of shading and high relative humidity, while the trees within the park reduce the heat stress level by one degree (from severe to medium, from medium to light or from light heat stress to comfort conditions).

Although lawn and trees created a cooling effect, the lawn was found to create uncomfortable human thermal sensation during the day and night mainly due to the lack of shading and high relative humidity, while the trees within the parks reduced the heat stress level by one degree (from severe to medium, from medium

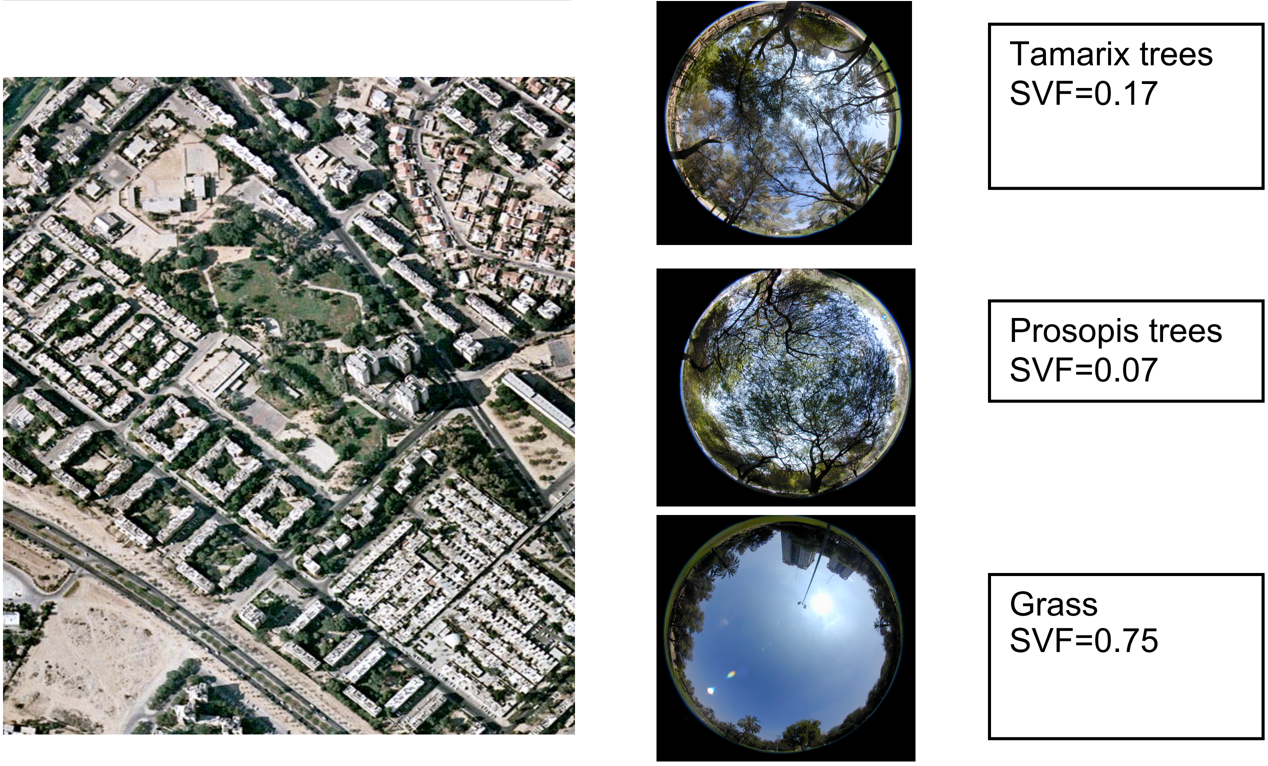

Figure 4: The urban park study site (left) and the characteristics of the investigated vegetation (right).

Table 2: The climatic behaviour of Tamarix trees, Prosopis trees and grass in an urban park June 7-11 2010 in the desert city of Beer Sheva, Israel.

Climatic variable	Tamarix trees	Prosopis trees	Grass	Built area
Max avg. air temp. T_a (°C)	31.7	32.3	33	34.6
Min avg. air temp. T_a (°C)	20.5	20.5	20.3	21
Max wind speed (m s^{-1})	1.8	1.1	2.3	2.4
Max avg. PET (°C)	40*	35*	42	44

to light or from light heat stress to comfort conditions)

4. Conclusions

It appears that in cities located in hot an arid climates, urban vegetation can play an important role in climate mitigation and therefore management is required in order to use suitable vegetation as tool for heat stress reduction.

According to the PET index, trees have been shown to make a significant improvement in human comfort in desert cities, while grass despite its small cooling effect made no significant improvement on human comfort

A larger heat stress mitigation effect caused by trees was observed where temperatures were the hottest.

Among the variables that influence the vegetation heat mitigation in the urban desert environment (ventilation, humidity, radiation etc.), the reduction of the Tmrt seems to have the largest impact.

Acknowledgement

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REFERENCES

Ali-Toudert, F., H, Mayer. 2007. Effects of asymmetry, galleries, overhanging façades and vegetation on thermal comfort in urban street canyons, Solar Energy. 81:742–754.

Baker LA, Brazel SW, Selover N, Martin C, McIntyre N, Steiner FR, Nelson A, Musacchio L. 2002. Urbanization and Warming in Phoenix (Arizona, USA): Impacts, Feedbacks and Mitigation. Urban Ecosystems 6:183–206.

Ben Shalom (Itzhak), H., Potchter, O., Tsoar, H., 2009. The effect of the urban heat island and global warming on thermal discomfort in a desert city, the case of Beer Sheva, Israel. Proceeding of the 7th International Conference on Urban Climate, Yokohama, Japan.

Brazel, S.W., Balling R.C., 1986. Temporal analysis of long-term atmospheric moisture levels in Phoenix, Arizona. J Climate Appl Meteor 25: 112–117

Dimoudi, A., Nikolopoulou, M., 2003. Vegetation in the urban environment: microclimate

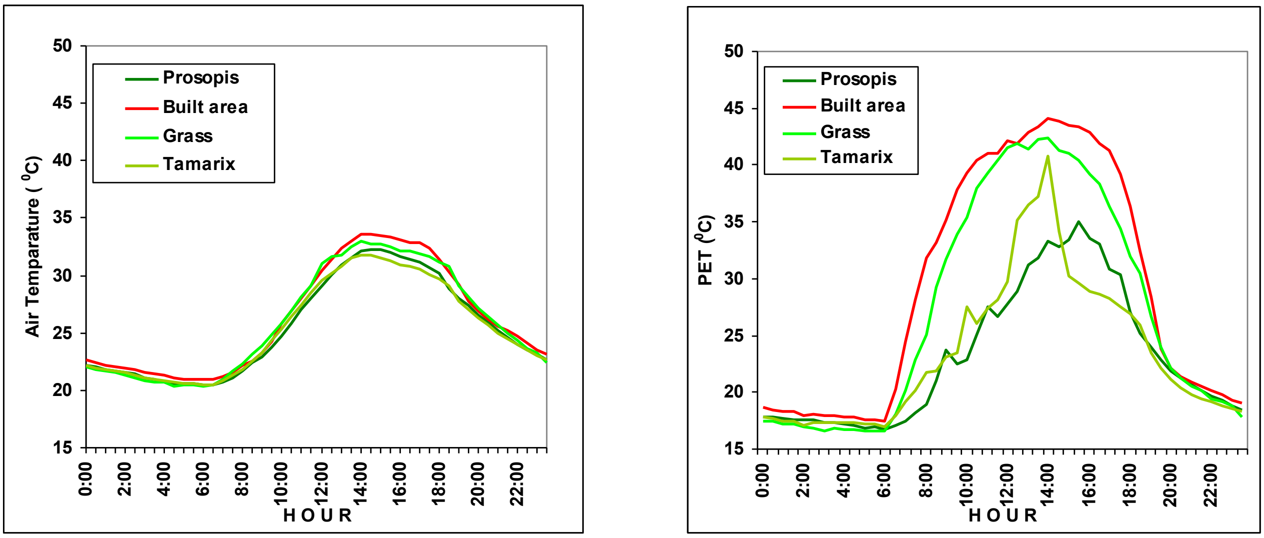

Figure 5: A comparison of average hourly temperature (left) and PET calculations (right) between Tamarix trees, Prosopis Trees, Grass and Built area from 13-18 June 2010, Beer-Sheva, Israel

analysis and benefits. Energy and Buildings 35: 69–76.

Elagib, N.A, 2010. Evolution of urban heat island in Khartoum, International Journal of Climatology, (in print) DOI: 10.1002/joc.2159

Emmanuel, R., Johansson, E.J., Rosenlund, H.. 2007. Urban shading – a design option for the tropics? A study in Colombo, Sri Lanka. Int. J. Climatol. 27, pp. 1995–2004

Givoni, B., 1991. Impact of planted areas on urban environmental quality: a review. Atmos. Environ. 25B (3), 289-299.

Grimmond, C.S.B., 2007. Urbanization and global environmental change: local effects of urban warming. Geographical Journal 173: 83–88.

Jauregui, E., 1991. Influence of large urban parks on temperature and convective precipitation in tropical cities. Energy and buildings, 15–16: 457–463.

Jendritzky, G., G, Menz., H, Schirmer. W, Schmidt-Kessen. 1990. Methodik zur räumlichen Bewertung der thermischen Komponente im Bioklima des Menschen. Beiträge der Akademie für Raumforschung und Landesplanung. Bd. 114, Hannover,

Mayer, H., A. Matzarakis, 2006. Impact of street trees on the thermal comfort on people in summer: A case study in Freiburg (Germany). Merhavim- Studies in the Geography of Israel and the Middle East, 5:285-300.

Matzarakis, A., Rutz, F., Mayer, H., 2006. Modelling radiation fluxes in simple and complex environments: basics of the RayMan model. Int. J. Biometeorol. 51(4):323-334

Miller, J.A., D.A. Hartz, B.C. Hedquist, C. Atkinson-Palombo, 2006. The role of vegetation, density, and sky view factor on the microclimate of Tempe, Arizona, USA. Proceeding of the Fifth International Conference of Urban Climate, Lodz, Poland. 366-369.

Robaa, S.M., 2004. A study of ultraviolet solar radiation at Cairo urban area, Egypt, Solar Energy, 77:251-259.

Potchter, O., Cohen, P., Bitan, A., 2006. Climatic behavior of various urban parks during hot and humid summer in the Mediterranean city of Tel Aviv, Israel. Int. J. Climatol. 26 (12), 1695-1711.

Shashua-bar, L., Potchter, O., Bitan, A., Bolanski, D., Yaakov, Y., 2010. Micro-climate modeling of street tree species within the varied urban morphology in the Mediterranean city of Tel Aviv. Int. J. Climatol., 30: 44–57.

Sofer, M., Potchter, O., 2006. The Urban Heat Island of a City in an Arid Zone: The Case of Eilat, Israel, Theoretical and Applied Climatology, 85(1-2):61-88.

Steemers K., 2003. Energy and the city: density, buildings and transport. Energy and Buildings 35: 3–14.

Tsiros, I, 2010. Assessment and energy implications of street air temperature cooling by shade tress in Athens (Greece) under extremely hot weather conditions. Renewable Energy. (In print)

Urban design and building regulation changes in the transformation of the urban block: A design analysis though the lens of urban climatology in Budapest

Csilla V Gal

1. Introduction

The knowledge of local climate was largely disregarded by urban planners in Budapest. Although attempts were made to bridge the gap between the design, the regulation and the climate of the city, due to the lack of knowledge, communication and political commitment all efforts were futile. One key attempt was Ferenc Probáld's seminal work on the climate of the capital (1974) that mapped mesoclimatic regions and described their possible use in planning. Approaching the issue from the other end of the urban scale, this paper focuses on the downtown blocks of Budapest. Through the examination of the spatial-physical outcomes of changing design and regulatory concerns, the essay intends to pinpoint regularity tools relevant for future climate-sensitive urban design and planning.

2. Brief history of the development of urban block typologies

The block of courtyard apartments

The regular urban block, comprising of back-to-back courtyard apartments, arise out of Pest's first planned expansion during the first half of the 19th century. Besides the financial forces, which channeled newly acquired commercial profits into property investments, three additional factors played a role in the emergence of this typology: the urban plan, the building ordinances, and the aesthetic preferences of the time. The plan of the district followed a general template for expansion; an undifferentiated grid of roads divided the land into urban blocks, which in turn were parceled out into regular building lots. The configuration of the lots—their size and close to square shape—was meant for apartment buildings and urban palaces. The 1839 Building Ordinance of Pest achieved a certain visual order through controlling both the range of applicable structures and the aesthetics appearance of buildings. The four-story neoclassical apartment building that emerged under these forces was organized around a central courtyard.

Over the second half of the century, late industrialization and consequent rapid urbanization caused soaring land prices within the city. The urban reconstructions across Europe influenced the course of Budapest's development in two ways. First, the examples governed the taste of residents who now regarded the short neoclassical buildings unfit for an emerging metropolis. This change in the aesthetic preference for taller buildings coincided with the economic rationale of rising land prices (Tomsics, 2007). Second, Haussmann's Paris made the look and the organization of streets the primary preoccupation of both professionals and interested laymen alike. As a consequence, discussions over the need for wider streets that both allowed for trees and separated side walks were frequently published. Similarly, various reports argued for adequate building height to

Figure 1: Blocks of courtyard apartments (Source: Google Earth, 2009)

street width ratios on the basis of hygiene and access to daylight (Tomsics, 2007). By that time though, speculation became the order of the day, and the exploitation of the land led to ever taller buildings with ever smaller courtyards.

The Metropolitan Board of Public Works—modeled after London's—was established in 1870 to supervise the planning and the regulation of the capital. Along with new building ordinances, the Board soon introduced bulk and use zoning. Although regulatory restrictions were set for building heights in relation to street widths and minimum allowable courtyard areas were defined, they were more the replication of international planning trends than genuine responses to public concerns. Over the last decades of the century, the typical apartment changed its style and grew by height but kept its fundamental organization around a central courtyard. Due to the insufficiencies in daylighting and ventilation of the courtyard-facing units, these tall historicist buildings became the focus of criticism for the century to come.

The emergence of the perimeter block

The growing social tensions due to worsening housing conditions made themselves increasingly felt during the first decade of the twentieth century. The criticism of dominant housing practices came from two sides. One side addressed the quality of living in courtyard facing dwellings (Bódy, 2004). The other condemned the unhygienic conditions and degrading morale caused by the housing shortage and increasing rents amongst lower-classes (Ferkai, 2003a). Continued rent hikes and evictions led to peaceful housing boycotts in 1907, which escalated into violent rent strikes between 1909 and 1910 (Gyáni, 1990; Moravánszky, 1998).

Architects and social reformers realized that in the short term housing reform would not be achieved through private capital (Ferkai, 2003a). Potential solutions were seen in alternative financing and new ownership structures. The encouragement of building societies for the middle classes and public housing provisions for the lower ones were proposed. The cooperative movement delivered the anticipated changes in housing, albeit to a rather limited section of the society. Civil servants were the only group in a position to bargain with financial institutions and to appeal for the necessary political support (Ferkai, 2003a). The cooperatives thus made the urban dwelling ideal—the perimeter block housing—possible well before the hygienically concerned regulations mandated them (Ferkai, 2003a).

The state lead the way in transforming the old laissez faire housing policy with the approval of a public housing project for its laborers. The resultant garden city type estate added some 4000 units to the capital. Within the same year, the Municipality of Budapest also launched its housing program. By 1913, the city increased its pool of public housing with approximately 6000 additional units (Moravánszky, 1998; Erdei, 1995). The program produced two kinds of dwellings: higher quality, larger apartments and cottages (Umbrai, 2007). The design of these apartment buildings formed a deliberate contrast to prevailing practices. The sparing use of ornamentation (Moravánszky, 1998), the reduction of building site coverage (Umbrai, 2007) and the experiments with building forms and urban block layouts were all intended to set an example.

The regulatory introduction of the perimeter block configuration was delayed by landowners who clung to their acquired building rights and opposed any changes that would reduce their profits (Ferkai, 2003a). The zoning and regulatory power was in the hand of the Metropolitan Board of Public Works—the majority members of which were nobility and haute bourgeoisie (Déry, 1995). Therefore, the Board members with real estate interests could likewise exert their influence by delaying reforms. Nevertheless, the Board also attempted to improve the quality of housing in a handful of cases. Influenced by the Viennese Ringstrasse development, joint courtyard configurations were specified for an urban block adjacent to Széll Kálmán Square in 1894 (Körner, 2010). Aimed for the well-to-do, the grouping of three–four neighboring building courtyards improved the daylighting of apartments, and for the better part, eliminated the rear and side wings, along with their tenants. The first perimeter configuration proposed by the Board was in 1906. Likewise aimed for the affluent, the rezoned urban block was located in the prestigious area near the City Park (Körner, 2010).

Regulatory reforms were also urged by progressive professionals at the Municipality's urban planning department. László Warga, the main proponent of perimeter blocks, recommended the application of this configuration for a whole neighborhood already in 1913 (Ferkai 2003a). Yet, despite the widespread criticism and attempts for reform, outdated courtyard apartments continued to be built until the end of the 1920s (Ferkai 2001). At that point, the conservative Board changed its stand and decided to incentivize perimeter block construction through tax credits. This was in place between 1934 and 1940, when a legal ban on courtyard apartment buildings was introduced.

The rise of the Zeilenbau configuration

By the time the perimeter block became accepted, it was already regarded inferior to the so-called Zeilenbau design, characterized by parallel rows of apartment buildings. The new generation of architects—influenced by Gropius—argued that the arrangement of terraced buildings along the edge of the urban block unavoidably results in north-facing rooms and problematic corner units that lack adequate sunlight and ventilation (Ferkai, 2001).

The wholesale urban renewal of inner Erzsébet-town, a district developed entirely in the manner of the detested blocks of courtyard apartments, was put forth by an idea competition in 1932. The participants were asked to present their redevelopment concepts at the scale of a single urban block. The winning team proposed two parallel rows of buildings, close to an ideal north-south orientation (Preisich, 2004; Bierbauer, 1933). Although the design was never realized, the concept sparked a debate about the Zeilenbau configuration (Preisich, 2004). The first parallel rows of buildings were built during the following years as part of an urban block redevelopment.

Figure 2: Perimeter blocks (Source: Google Earth, 2009)

Figure 3: Blocks of row apartment houses (Source: Google Earth, 2009)

Since neither the traditional row-house configuration nor the modern Zeilenbau were native to Hungary, local regulations lacked both the necessary ordinances and the areas dedicated to them. The 1933 amendments to the building code were the first to allow these linear urban configurations. However, according to both this one and the following 1940 Building and Zoning Ordinance of Budapest, the Zeilenbau construction was tied to certain conditions. The permission was given upon request only, if the development of an entire urban block—in a uniform manner—could be ensured, and if a close to north-south building orientation could be achieved (Harrer, 2006).

The communist governmental take over, after the Second World War, changed the operation of the construction industry profoundly. As state planning mechanisms were introduced to housing production, architecture and urban planning began to be judged on the basis of economic efficiency and output (Preisich, 1998). Therefore large housing estates were built on superblocks. Although the application of row- and pavilion-shaped buildings prevailed until the end of this era, starting from the 1960s, the rigid composition of north-south oriented parallel rows of buildings was slowly abandoned (Körner, 2006).

The emergence of hybrid forms

During the 1970s, critics argued for a qualitative, rather than quantitative approach to meeting housing needs (Preisich, 1998). With the diminishing role of the state during the last decade of communism, architects and planners broke with the prevailing schematism in housing and returned to a more human scale (Körner, 2006). The 1990s brought a sea of changes from the governmental system to the economic structure of the country. With the rise of market forces came the need to rebrand the concept of housing estates. The coined term lakópark (housing park) was the outcome of the revived real estate industry that desperately tried to avoid the term estate—now

Figure 4: Urban blocks with clusters of pavilions (Source: Google Maps, 2009)

filled with negative connotations (Körner, 2006). The lakópark covers no specific spatial configuration, but its function is reminiscent of western gated communities (Vámosi, 2003).

The urban housing forms that emerged over the past two decades were shaped by regulations, profit and the inventiveness of architects to marry the two. To be profitable, the new developments required economies of scale, often covering entire urban blocks. The need to accommodate a large number of small dwellings, combined with the abolition of daylighting requirements, lead to the popularity of the double-loaded corridor layout—a configuration found in typical hotels (Körner, 2006). New real estate trends also dictated condominium towers with balconies. However, these demands were often in conflict with local regulations that applied height restrictions and required perimeter-type developments. A characteristic outcome of these conflicting forces was the form that can be best described as an block-size base with several mid-rise pavilions atop (Körner, 2006). The introduction of the base overcame not only the perimeter block requirement, but improved the profitability of the project as well. Since the short towers were connected by their base—therefore treated as an ensemble, rather then as separate pavilions—they were exempt from regulations that would have otherwise demanded much larger distances between them (Körner, 2006).

3. Discussion and Conclusions

The microclimates of urban spaces are influenced by human activities, vegetation and by the spatial configuration and physical properties of their bounding surfaces. In the Hungarian regulatory system governing the built environment several measures already exist that influence these parameters. The emitted heat—due to human activities such as space heating, automobiles, etc. —is primarily a function of land use and zoning. The amount and distribution of green areas is outlined in the Green Area Development Concept of Budapest; the vegetation cover on lots for building is defined by the green area ratio, specified by zoning ordinances. Spatial configuration and building density are governed by the zoning ordinances as well. The main planning tools in this manner are building heights, plot ratios and lot coverage restrictions along with allowable built forms. The main properties of urban surfaces involved in the development of microclimates are the thermal mass, thermal conductivity and reflectivity (albedo). The conductivity of building structures is regulated by the national building code through U-value specifications. Whereas these values are universally mandated, surface reflectivity is only dealt with in regulatory plans of protected areas in a rather indirect manner—they control the pavements of streets and the colors of the facades. As for the thermal mass of buildings, currently there are no means to influence them.

The regulations developed over the past century provide a solid framework for the integration of climate knowledge into the planning process in Budapest. The 19th century planning focused its efforts entirely on the design and embellishment of streets and delivered concepts and tools to actively shape the city. Regulations such as building height to street width ratios and the tree-lined avenue ideal were all characteristic outcomes of the era. The foundations for a housing reform were laid down over the first decades of the next century, when rising public heath concerns lead architects and planners to look for new solutions. As the market failed to produce adequate homes, professionals moved beyond the public realm to regulate the configuration of urban blocks. Among others things, the concept of the rear building line and the lot coverage index were the achievements of these efforts. A new approach to urban planning and housing emerged during the 1930s. Influenced by German developments, this wave of professionals aimed at integrating the emerging knowledge of science and technology into the design and organization of cities. The desire to democratize healthy dwelling led to concepts such as universal access to sunlight, fresh air and green spaces. Out of the concern for overcrowding arose the aim for a conscious distribution of the urban population and the idea of graduated zoning —the gradual allocation of decreasing building densities from the city center to the urban periphery.

In the 1930s, when planners first called for solar maps and other climatic data in order to incorporate them into the design of the city, urban climatology was still in its infancy and could not fulfill these requests. The second attempt to bring the two professions together would not occur until the 1970s. Driven by the then established science, Ferenc Probáld proposed the conscious use of mesoclimatic regions in urban planning (Probáld, 1985). However, amidst the fading role of the government during the 1980s and the subsequent sea of political changes, only ambiguous declarations remained—stressing the need for climatic considerations in planning—without the essential know-how or understanding. Yet, as the bulk of necessary tools are already part of the regulatory framework, and there is a coming together of concerned professional from all sides, the possibility for the implementation of a climate sensitive urban planning is perhaps much closer now than at any other time in history. From the perspective of planners and architects, further microclimate studies are needed to understand how certain urban configurations interact with the local climate. It is time to move beyond the optimized single building design paradigm, in order to re-learn the knowledge that was forgotten with the introduction of the mechanically controlled environment.

REFERENCES

Bierbauer, V., 1933. Városi telektömbök ujjáépítése [Reconstruction of urban blocks]. Tér és Forma, 6(3), pp.122–126.

Bódy, Z., 2004. Kislakás, társasház, családi ház: lakáséptkezés és az otthon ideáljának változása Budapesten az első világháború körül [Small-house, condominium, single family home: dwelling constructions the change of home ideals in Budapest around the First World War]. Századvég, 9(34), pp.27–57.

Daunton, M.J., 1990. Housing the workers, 1850-1914: a comparative perspective, London and New York: Leicester University Press.

Déry, A., 1995. A Fővárosi Közmunkák Tanácsa (1870-1948): Egy független városrendező hatóság [The Metropolitan Board of Public Works (1870-1948): An independent planning authority]. Budapesti Negyed, 3(3), pp.77-96.

Erdei, G., 1995. A mintaadó polgármester: Bárczy István beruházási programja, 1906-1914 [The exemplary Mayor: István Bárczy's investment program, 1906-1914]. Budapesti Negyed, 3(3), pp. 97-116.

Ferkai, A., 2003a. A társasház, mint a budapesti lakóházépítés megújításának egyik módja [Condominium as way to housing reform in Budapest]. In Űr vagy megélt tér [Space or lived place]. Építészet/elmélet. Budapest: Terc, pp. 103-123.

Ferkai, A., 2001. Pest építészete a két világháború között [The architecture of Pest between the world wars], Budapest: Modern Építészetért Építészettörténeti és Műemlékvédelmi KHT.

Ferkai, A., 2003b. Űr vagy megélt tér: építészettörténeti írások [Space or lived place: writings on architectural history], Budapest: Terc.

Google Earth, 2009. Urban blocks of Budapest. Google, Inc., Mountain View California. Available at: http://maps.google.com [Accessed October 15, 2009].

Gyáni, G., 1990. Budapest. In M. J. Daunton, ed. Housing the workers, 1850-1914. London and New York: Leicester University Press, pp. 149–181.

Harrer, F., 2006. A Fővárosi Közmunkák Tanácsa: 1930 - 1940 [The Metropolitan Board of Public Works: 1930 - 1940, Ép\ítésügyi Tájékoztatási Központ.

Körner, Z., 2010. Városias beépítési formák, bérház- és lakástípusok [Urban built forms, housing and dwelling types], Terc.

Körner, Z. & Nagy, M., 2006. Az európai és a magyar telepszerű lakásépítés története 1945-től napjainkig [The history of housing estates from 1945 until present in Hungary and Europe], Budapest: Terc.

Moravánszky, Á., 1998. Competing visions: aesthetic invention and social imagination in Central European architecture, 1867-1918, Cambridge MA: MIT Press.

Preisich, G., 2004. Budapest városépítésének története: Buda visszavételétol a II. világháború végéig [History of the urban development of Budapest: from the recapture of Buda to the end of the Second World War] 2nd ed., Budapest: Terc.

Preisich, G., 1998. Budapest városépítésének története, 1945-1990: tanulmányok [History of the urban development of Budapest, 1945-1990: studies], Budapest: Műszaki Könyvkiadó.

Probáld, F., 1974. Budapest városklímája [The urban climate of Budapest], Budapest: Akadémiai Kiadó.

Probáld, F., 1985. Urban climate and urban planning in Budapest. Geographical Papers, 6, pp. 139-145.

Tomsics, E., 2007. Valóság, tervek, ábrándok: civil vélemények és elképzelések Buda-Pestről az 1860-as években [Reality, plans, dreams: laymen opinions and imaginations of Buda-Pest during the 1860s]. Budapesti Negyed, 15(2), pp.147–178.

Umbrai, L., 2007. A hatósági kislakásépítés története Budapesten (1870-1948) [The history of municipal small-house construction in Budapest (1870-1948)]. PhD Thesis. Eötvös Loránd Tudományegyetem, Bölcsészettudományi Kar. Available at: http://doktori.btk.elte.hu/hist/umbrai/disszertacio.pdf.

Vámosi, D., 2003. Fogyasztás és lakásépítés: a lakóparkok viága, 1. rész [Consumption and housing: the world of housing parks, part one]. Kortárs építészet, 5(2). Available at: http://arch.eptort.bme.hu/18/18vamosd.html

City Weathers in Aachen during the 1800s

Katja Eßer

I. Introduction

HumTec is an interdisciplinary Project House at RWTH Aachen University, funded by the Excellence Initiative of the German Federal and State Governments. HumTec aims at fostering high level interdisciplinary research between humanities/social sciences and engineering/natural sciences. There are seven programmes with different research topics. Using the city of Aachen as a case study, the team of City 2020+ has been analysing the interrelation among climatic circumstances, urban building structures and the residents' health status since spring 2009. The sub-project on environmental history accordingly concentrates on the strategies of inhabitants, of the manufacturers amongst them, the governance and urban planners for coping with environmental conditions and meteorological events during the 19th century. This paper's objective is to give an insight in some results of the current research for my doctoral thesis.

Around 1800, Aachen's topography was very similar to the current: the oldest urban structure with the cathedral and the town hall at its heart is located in a basin with a diameter of approx. 10 km that opens up only north-eastwards. On the southern fringe, the city centre (about 160-200 m above sea level) is bordered by a hilly wood (385 m) and in the northwest by the connected ridges of three hills called Lousberg (264 m), Salvator- and Wingertsberg. Two parallel thrust faults cross the urban region and several thermal springs surface alongside them, providing the city with the hot and highly mineralised waters it is famous for. Ranges of higher areas around the city imbed suburban creek valleys that converge towards the centre. The climate can be described as maritime with mild winter temperatures and moderate warm summers.

Based on fundamental structures dating back to the Romans, Carolingians and the Middle Ages, Aachen's urban ground plan resulted from the siting of the thermal springs and the radial street layout orientated towards the trade routes to Cologne, Liège, Jülich and Maastricht. Above all, production and trade of woollen cloth, of course accompanied by ancillary industries, were the primary historical sources of the city's economic wealth since the Middle Ages.

With early examples dating back to the 15th century, building regulations certainly affected Aachen's appearance as well. They were often issued in response to occasional instances such as conflicts about privation of air and light by neighbouring houses (Schmitt, 1972, p. 48). After a devastating town fire in 1656 that destroyed the medieval building structure, advanced restrictions concerning fire safety were issued (Kunitz, 1994). In the following century, Aachen – who's name can be traced back to antique terms for "water" – was reconstructed as a spa town, based on the medicinal background of the writings by the balneologist François Blondel. A guidebook for spa guests from 1762 describes remarkable features: a building density not high enough to obstruct ventilation plus numerous gardens and meadows within the city walls, spaces for cultivating vegetables and fruits (von Koppen, 1996, p. 11).

II. The change of Aachen's urban layout during the 1800s

The period under consideration spans from the loss of Aachen's status as a free imperial city of the Holy Roman Empire and the Napoleonic occupation to the eve of the First World War. Between these years of 1794 to 1914, the city underwent fundamental changes, caused by the structural policy of the French and later Prussian administration and – compared to other German towns – by a very early onset of industrialisation. Among technological and economical changes at a hitherto unknown pace, the processes of industrialisation, urbanisation and eruptive modernisation strongly influenced both building and social structures.

Decisions on the urban layout during the 19th century always had to take into consideration requirements that the two conflicting centuries-old traditions and self-conceptions imposed on the socioeconomic development: Aachen was both a health resort and an industrial city. Thus, investments in spa facilities and the imprint of industrial business took place simultaneously. Fountains and bathhouses, the theatre, the railway and the "Polytechnikum" (first Prussian institute of technology in the Rhine Province) modified Aachen's urban appearance.

The Napoleonic government initiated the process of breaking down the city walls and watch towers and giving those parcels of land a new shape as promenades and green areas. Until the 1860s, the increasing development first filled up the available open spaces of former meadows and vacant lots within the 175 hectares of the historic centre before reaching beyond the former city limits. The first modern building regulation of 1826 was mainly focused on a new street reaching from the theatre to the neighbouring town. The following regulations of 1853, 1872 and 1900 included statutory provisions concerning fire safety and building stability, limitations of building sizes on certain properties and the ratio of the breadth of streets to the height of houses. But there was no general plan that defined the urban development of the entire city or classified specific land-use areas. The foundation and composition of new quarters beyond the city walls must be ascribed to entrepreneurial initiatives. Earlier structures, e.g. roads and promenades leading from the centre to the previously open landscape, were truncated by those quarters (Sokull, 2010, pp. 112, 116).

III. Meteorological knowledge and urban hygiene

The early beginnings of modern meteorological observation in Aachen date back to the 1820s, according to statements in retrospect by Peter Polis (Polis, 1896). These old data series he refers to seem to be results of a quite exclusive leisure activity of physicians, teachers and balneologists. But some of those observers examined the correlation of urban hygiene, topography and weather conditions:

Mathias Debey (1817-1884) was a member of the "Ortssanitätskommission" (municipal medical board), head of the quarantine station during two cholera epidemics (1855, 1866) and the variola epidemic in 1881. In a medical-topographic study on malaria (Debey, 1877), he proved its endemic occurrence in certain groups of houses over decades. He ascribed this finding not to the dense population, but to the location of those quarters at a specific altitude (Lenzen, 1979, p. 63). In retrospect, the "breedingplace" of malaria can be identified as a pond, continuously fed with hot thermal water until it was drained in the late 1830s (Boventer, 1957). Although the role of the anopheles mosquito as transmitter was yet undiscovered, stagnant water with its evaporations and offensive smell especially in summer was frequently suspected as disease-causing.

The second weather observer, Ignaz Beissel sen. (1820-1877), natural scientist and geologist, was commissioned in 1866 by the city administration to examine samples of well water from several residential houses that were sites of cholera outbreaks during each epidemic. His study (Beissel, 1866) is a significant document of the contemporary discussion on the "contagium", since he tried to figure out the interplay of soil, ground water, leaky water supply facilities and wastewater canals in the transmission of that disease.

Finally, Johann Gerhard Joseph Schervier (1821-1892), balneologist and physician at several hospitals, recorded over twenty years of meteorological observation, as Lenzen (1979, p. 189) states, "in the context of studies on urban hygiene conditions". Although the exact measurement setup used by those "ancestors" of meteorology in Aachen can not easily be reconstructed, these scientists – who were members of the public administration as well as scientific societies – presumably had a high interest in the nexus of climatic factors and urban hygiene (Ketzler, Eßer and Paffen, 2010). The advancement and professionalisation of meteorology in Aachen during the 1800s was concluded by the foundation of an observatory in a municipal park in 1900, managed by Peter Polis (1869-1929) (Polis, 1900).

IV. Living conditions and their influence on human health

One single representative of a certain type of historical source, medical descriptions of cities and their environment, is extant. The physician Friedrich Ernst Hesse described climate, topography, housing and working conditions in Burtscheid, Aachen's neighbouring town, at the very beginning of the industrial revolution (Hesse, 1804). For the working class, the last-mentioned parameters were eminently poor, so were health and safety, and they didn't improve for seventy years, until modern infrastructural facilities (new sewage system, drinking water pipelines etc.) were installed (Heuser, 1900; Savelsberg, 1900; von Montigny, 1913). As archival sources and historical maps document, the factory owners' residences, their cloth mills and dye works with steam engines and the overcrowded working class quarters with poor sanitation, low air quality and characteristic diseases (cholera, abdominal typhus, variola) were situated closely in the city centre throughout the 19th century. Pondering two simultaneous development trends, the aggravation becomes clear: The population increased sixfold between 1794 and 1900, reaching 132.245 inhabitants (Poll and Siemons, 2003, p. 235) while the construction of new factories was not forbidden until 1900. The new building code of that year, which included the interdiction, initially differentiated specific land-use areas with a gradation from inner to outer urban disctricts (Sokull, 2010, p. 162).

In the early 19th century, Aachen had been in an exceptional legal position amongst German industrial cities, since a certain Napoleonic edict from 1810 remained in effect under the Prussian government. The edict not only stipulated a standard procedure for concessions of new companies and machines, it also introduced the idea of striving for a physical separation of business enterprises and residential areas by classifying factories with regard to their emissions and determining a certain distance to housing units. This edict was the legal background and benchmark of numerous complaints by residents about the noxious effects caused by industrial plants and their steam engines. The local disputes of the 1820s led the city administration to propose a bill on concessions and operation conditions of steam engines. Subsequently, the royal Prussian authorities had to deal in laws and regulations with the so-called “smoke and soot plague” that endangered public health (Mieck, 1967 and 1982; Uekötter 2003; Spelsberg, 1984). For Aachen as a spa town and tourist destination, the severe environmental impairment caused by the metal-working industry in nearby Stolberg (Stolberg, 1994) was a deterrent example. An area grounded in heavy industry (smelter “Rothe Erde”, machinery and railway wagon construction companies) was established beginning in the 1840s in the north-east, corresponding indeed with the prevailing wind direction (south/southwest), but the decisive factor was the area's topography with plain and undeveloped ground. It was around 1910 when finally, in contrast to researchers rising premonitions of atmospheric contamination, other experts did not rate the air quality as heavily afflicted. Their arguments were: Aachen's moderate size, the spacious development, solely local smoke sources and domestic use of lean coal. They argued that wind and rain as climatic factors counteracted the accumulation of deleterious gases (Aachen, Stadtarchiv, file OB 15/2 I). Those different sources must be carefully considered, since a quantification of pollutants released over 100 years ago is impossible and oral history testimonies (e.g. Emunds, 1989) are only reliable with some reservations. Considering the translocation of many heavy industrial companies to the Ruhr region in the late 1800s, the “smoke and soot plague” seems to have been less grave in the city of Aachen around 1900.

V. Application of urban climatology today

Keeping wind in mind as an important factor of urban climate, a concluding outlook and linkup with current climate research may be added. The siting of Aachen in a round basin, approx. 100-200 metres below the surroundings, can be problematic in anticyclonic weather situations, since a temperature inversion may lead to limited air exchange and thus an accumulation of airborne pollutants in the basin. The importance of the valleys in the south as cold air drainage flows towards the city centre was recognised in the last decades (Pflug, 1978; Emonds, 1986). It was

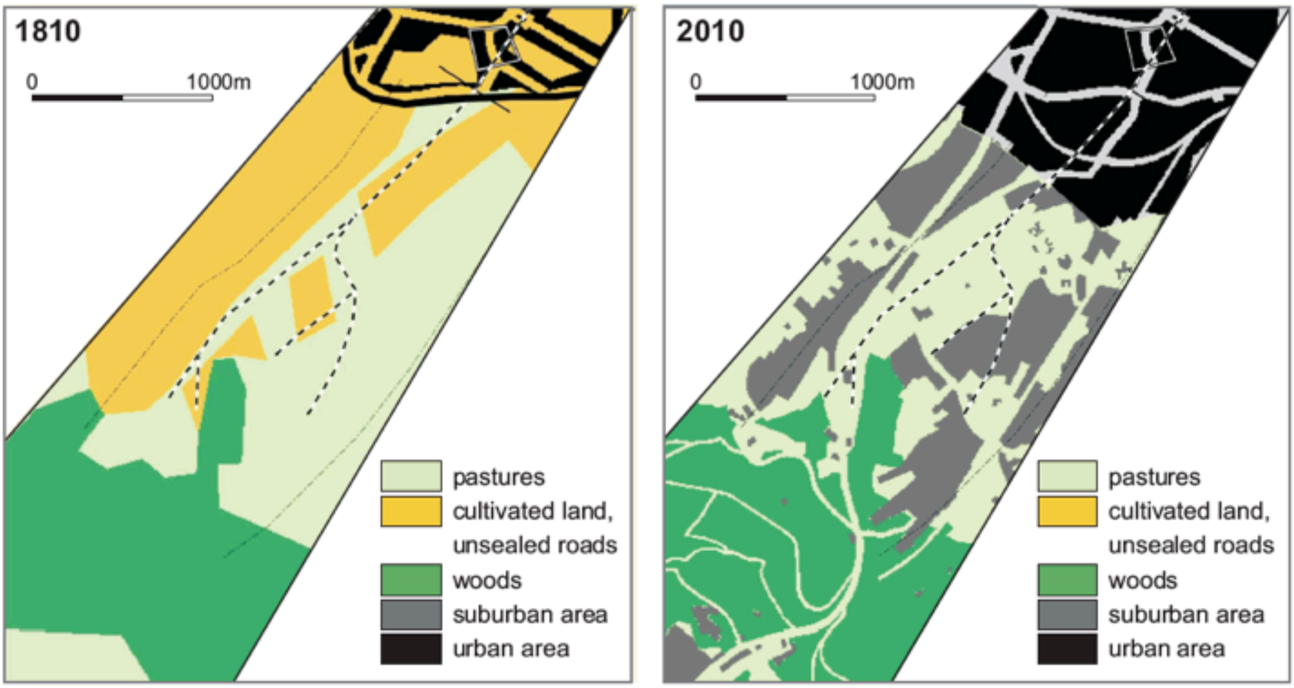

Figure 1: Change of land use in the south-western part of Aachen between 1810 and 2010 (dashed lines: valley axes with cold air drainage flows towards the city centre) (Ketzler, Eßer and Sachsen, 2010).

considered in an integrated urban climate assessment with a climate function map of 2001, which was subsequently relevant to regional planning (Havlik and Ketzler 2000). An interdisciplinary study including historical maps, picture sources and a digital elevation model just recently examined the changed conditions for one major cold air drainage flow. Urban development between 1810 and 2010 – increased building density and built-up area – has caused a considerable decrease of its positive biometeorological effects such as a nocturnal cooling effect and an improvement of air quality (Ketzler, Eßer and Sachsen, 2010) (see Figure 1).

The team members of the project City 2020+ will conclude their research in spring/summer 2012.

Concerning the integration of climatological knowledge in current urban planning: Since April 2010, a working group is preparing a new “Masterplan” (as an informal working plan) and a formal land-use plan in cooperation with the city administration (Aachen*2030).

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REFERENCES

- [several authors], 1910-1923. File on “Bekämpfung der Rauch-und Rußplage”. OB 15/2 I. Aachen. Stadtarchiv.
- Beissel, I., 1866. Mikroskopische Untersuchung der Brunnenwasser einiger Cholerahäuser der Stadt Aachen ausgeführt im Jahre 1866 [manuscript]. HS 952. Aachen. Stadtarchiv.
- Boventer, K., 1957. Das Wechselfieber in Alt-Aachen und Burtscheid – Burtscheider Krankheit. Zeitschrift des Aachener Geschichtsvereins, 59, pp. 111-122.
- Debey, M., 1877. Die intermittirenden Fieber und verwandte Krankheitsformen in Aachen in den Jahren 1830-1865. Eine medicinisch-topographische Studie. Aachen. Stadtbibliothek.
- Emonds, H., 1986. Klimatologische Beurteilungsgrundlagen zur Berücksichtigung der Luftreinhaltung bei der städtebaulichen Planung in Tallagen, Aachen.
- Emunds, P., 1989. Rauchfahnen – Streikfahnen – Staubfahnen auf Rothe Erde, über Eilendorf, Forst und Nirm. Aachen.
- Eßer, K., 2010. Hintergründe der klimatologischen Messungen in Aachen im 19.

Jahrhundert. Aachener Geographische Arbeiten, 47, pp. 31-33.

- Havlik, D., Ketzler, G., 2000. Gesamtstädtisches Klimagutachten Aachen, Aachen.
- Hesse, F. E., 1804. Einige medizinische Nachrichten und Bemerkungen über Burtscheid bei Aachen, Aachen.
- Heuser, G., 1900. Entwässerung der Stadt. In: Festschrift zur 72. Versammlung Deutscher Naturforscher und Ärzte, Aachen, pp. 142-157.
- Ketzler, G., Eßer, K. and Paffen, M., 2010. Chronik der klimatologischen Messungen in Aachen. Aachener Geographische Arbeiten, 47, pp. 24-30.
- Ketzler, G., Eßer, K., and Sachsen, T., 2010. Veränderung von Belüftungsfunktionen durch lokalen Kaltluftabfluss im Zuge historischer Stadtentwicklung
- eine Modellstudie Aachen 1810-2010. Aachener Geographische Arbeiten, 47, pp. 77-98.
- Kunitz, C., 1994. Aachen nach dem Stadtbrand. Wege und Maßnahmen zum Wiederaufbau 1656-1661. Master thesis. RWTH Aachen.
- Lenzen, D., 1979. Beitrag zur Aachener Medizinalgeschichte des 19. Jahrhunderts. Ph. D. Aachen.
- Mieck, I., 1967. “Aerem corrumpere non licet”. Luftverunreinigung und Immissionsschutz in Preußen bis zur Gewerbeordnung 1869. Technikgeschichte 34 (1), pp. 36-71.
- Mieck, I., 1982. Umweltschutz zur Zeit der frühen Industrialisierung. In: H. Kellenbenz, ed. 1982. Wirtschaftsentwicklung und Umweltbeeinflussung (14.-20. Jahrhundert). Berichte der 9. Arbeitstagung der Gesellschaft für Sozial-und Wirtschaftsgeschichte, Wiesbaden, pp. 231-245.
- Pflug, W. ed., 1978. Landschaftsplanerisches Gutachten Aachen, Aachen.
- Polis, P., 1896. Ergebnisse der meteorologischen Beobachungen. Deutsches Meteorologisches Jahrbuch für 1895, Aachen.
- Polis, P., 1900. Die Entwickelung der Meteorologie unter besonderer Berücksichtigung der Aachener Station im neunzehnten Jahrhundert. Festrede bei der Einweihung des Meterologischen Observatoriums auf dem Wingertsberg im Stadtgarten zu Aachen, gehalten am 22. September 1900 im Instrumentensaale des Observatoriums von dessen Direktor, Aachen. Hochschulbibliothek RWTH Aachen.
- Poll, B., Siemons, H., 2003. Geschichte Aachens in Daten. Aachen.

Savelsberg, K., 1900. Die Entwickelung der Wasserversorgung der Stadt Aachen. In: Festschrift zur 72. Versammlung Deutscher Naturforscher und Ärzte, Aachen, pp. 130-142.

- Schmitt, M., 1972. Die städtebauliche Entwicklung Aachens im Mittelalter unter Berücksichtigung der gestaltbildenden Faktoren. Ph. D. RWTH Aachen.
- Sokull, J., 2010. Aachener Stadtbauplanung. Baurecht und kommunale Selbstverwaltung im 19. Jh. und ihr Einfluss auf die Stadterweiterung am Beispiel der Stadt Aachen, Ph. D. Aachen.
- Spelsberg, G., 1984. Rauchplage. Hundert Jahre Saurer Regen, Aachen.
- Stolberg, M., 1994. Ein Recht auf saubere Luft? Umweltkonflikte am Beginn des Industriezeitalters. Erlangen.
- Uekötter, F., 2002. Von der Rauchplage zur ökologischen Revolution. Eine Geschichte der Luftverschmutzung in Deutschland und den USA 1880-1970. Essen.
- von Koppen, B., 1996. Alt-Aachener Gärten, 2nd ed. Aachen.
- von Montigny, K., 1913. Die Kanalisation und die biologische Kläranlage. In: Die Gesundheitspflege in Aachen. Festschrift der Stadt Aachen zur 38. Versammlung des Deutschen Vereins für öffentliche Gesundheitspflege, Aachen, pp. 99-125.

Urban design codes for Mediterranean cities: The need for implementing climatic considerations

Tali Hatuka and Hadas Saaroni

1. Human comfort and climate change in the Mediterranean Basin

The Mediterranean Basin (MB), located at the border between Mediterranean (temperate) and arid climatic regions, is one of the key regions of high anthropogenic climate impact (Lionello et al., 2006; IPCC, 2007). In particular we look at the Tel Aviv-Jaffa metropolitan area, located at the eastern coast of the MB.

This area is characterized during the summer by high temperatures and relative humidity (RH). The RH has considerable contribution to heat stress (HS), as is reflected in various HS indices (Willett et al., 2007; Ziv and Saaroni, 2011). According to the Temperature Humidity Index of McGregor and Nieuwolt (1998), the typical summer midday conditions in Tel Aviv, i.e., 30°C and 70% RH (Bitan and Rubin, 1994), are defined as "discomfort conditions for all humans" (McGregor and Nieuwolt, 1998). Potchter et al (2006), using the PMV thermo-physiological index (Fanger, 1970; Jendritzky et al., 1990) has shown medium to severe heat stress conditions in Tel Aviv city during the summer. Discomfort conditions are further aggravated by the urban heat island (UHI) effect that is well developed in Tel Aviv (Ben-Dor and Saaroni, 1997; Saaroni et al., 2000).

Climatic studies point at a significant warming trend, larger than the global rate, in the summer months over the majority of the MB along the last three decades (Saaroni et al., 2003; Xoplaki et al., 2003; Luterbacher et al., 2004; Ziv et al., 2005; Baldi et al., 2006; IPCC, 2007). Moreover, Ziv and Saaroni (2011) argue that temperature increase is expected to increase the air stability over the MB, manifested by an intensification of the marine inversion, and its ability to trap the lower level moisture and air pollutants. This further aggravates the HS conditions, leads to higher energy consumption (for cooling) and to further enhancement of the urban heat island effect and air pollution. Aggravation of heat waves and heat stress conditions has severe environmental impacts on human comfort as well as on the hydrological cycle and water shortages (Alpert et al., 2002; Lionello et al., 2006; Ziv and Saaroni, 2011).

Moreover, climate models for the 21st century forecast intense warming (Meehl and Tebaldi, 2004; IPCC, 2007) together with decreased precipitation over the eastern MB (Lionello and Giorgi, 2007; Krichak et al., 2007; Giorgi and Lionello, 2008; Raible et al., 2010) that will further aggravate discomfort conditions and water shortages. Thus, from the perspective of environmentalists in general and climatologists in particular, there is an urgent need to incorporate climate considerations into planning and design practices, especially in open areas such as urban parks.

2. Climate considerations in planning

With growing recognition by policy makers, planners and the public as a whole regarding climate change and global warming, it is expected that climate considerations would have a growing impact on spatial planning. Recent analysis of the interrelationships between landscape planning and climate conditions, from the individual unit and the city as a whole, advocate an urgent need for integrating this knowledge into practice (Aronin, 1953; Evans, 1980; Park, 1987; Evans and

Schiller, 1996; Golany, 1996; Wheeler, 2004; Wheeler and Beatley, 2004; Register, 2006; Pearlmutter, 2007; Farr, 2008).

Most studies focus on design issues, helping to settle disputes about site orientation, site organization, and the assembly of building materials (Givoni, 1998). More specifically, two key trends of studies are identified: (1) buildings' analysis from a climatologic perspective, focusing on the effect of architectural and structural design features (e.g., layout, window orientation, shading and ventilation) on human thermal comfort in indoor environments; (2) urban analysis that explores the effects of city design and the spatial array (i.e. density, building height, street geometry), on human thermal comfort in outdoor environments. Yet, though these studies vastly explored the relationships between the built environment and climate (Givoni, 1976, 1991; Oke, 2006; Potchter, et al., 2006), it seems that the transfer of climatic knowledge into planning practice, particularly of open public areas such as urban parks, is still lacking.

Aiming at finding the reasons for this gap between scientific knowledge (theory) and local landscape planning (practice), scholars pointed to technical, political, social, economic and organizational constraints (Eliasson, 2000). However, it seems that this argument is too broad. From the point of view of the planner, who mediates among different actor's needs within the limits of a strict budget, all plans represent a sort of reductionist visual manifestation of wills and constraints (Hatuka, 2010). Referring to the process of decision making in planning, scholars suggest that this gap is linked to the decentralization of planning and distrust toward experts (Beunen and Opdam, 2011). This decentralization is embedded in a broader epistemological change, which deviates from the universal generic models working toward the adaptation of a local knowledge (Escobar, 1998; McNie, 2007; Hatuka, 2010).

These ideas express the need to investigate which criteria influence the process of planning and why, in spite of wide climate knowledge and planner's recognition of the need to support human comfort, especially in an era of global warming, climate considerations are often being placed at the bottom of spatial planning priorities.

3. Parameters that influence the design and planning of urban parks

Analyzing the scope of climate considerations for planning and design practices, a key typological space was chosen, the urban park. Viewed as a recreational and visual asset to a community, the urban park supposes to support human comfort, social needs and thus addresses climate considerations in the process of design (Miller, 2009). Yet, this rather traditional perception of the park, as recreational space, has been challenged recently by researchers who emphasize the role of the contemporary urban park as a valuable contributor to larger urban policy objectives, such as increasing property value, supporting youth development, enhancing public health, and advancing community building (Spirn, 1998; Waldheim, 2006; Harnik, 2010). Along with recreational goals, urban parks have a significant visual impact on users, especially in contemporary dense cities. Parks provide not just a physical place, but an aesthetic image (Meyer, 2008; Dee, 2010; Jorgensen, 2011), which has an economic, social and cultural impact on adjacent areas. These multiple roles and prospective benefits of the contemporary park transform it into a primary social asset that (might) enhance diversity and support social and economical development (Walker, 2004). Clearly, this definition has changed the use of scientific knowledge as well as the priorities and parameters that influence the design of the contemporary urban park.

From the comfort point of view, Potchter et al. (2006) studied the climatic and comfort conditions Tel Aviv urban parks during the hot and humid summer season. They show that urban parks with high and wide-canopied trees, have the maximum cooling effect during the hottest hours of the day and have a positive effect on human climatic comfort whereas parks with grass and only a few low trees are warmer than the surrounding built-up areas and thus have a negative effect on human climatic comfort during the day. Moreover, they have found that urban parks in the hot and humid coastal Mediterranean climate are 'humidity islands' but not necessarily cool islands as suggested by Oke (1987) and Spronken-Smith and

Oke (1998). Their results suggest avoiding parks with grass coverage and without trees in a coastal Mediterranean area.

4. The case study of the new Jaffa Slope Park

Acknowledging this change in the role of urban park, we focus on the Jaffa Slope Park, a 50-acre (200 dunam) waterfront park in Tel Aviv-Jaffa, Israel opened in April 2010. Being supported by public funding and resources (rather than private donors) and regulated by the city council, one might think that in an age of decentralized planning and neo-liberal economic, public authorities would be the ones more likely to show sensitivity toward climate change, climatic discomfort conditions, water shortages, etc. Thus, our basic hypothesis is that an increase in discomfort conditions resulting from aggravation of heat stress, heat waves, and water shortages would lead planners to comprehensively respond to this change, thus resulting in increasing implementation of climate considerations in the process of parks' design, such as reduction of areas requiring drinking water for irrigation and addressing the aggregation of discomfort conditions, including the allocation of trees or pergolas for shade, drinking fountains and wind considerations.

The Jaffa Slope Park, claimed to be a large environmentally friendly and social project raises contradictory issues. Socially, despite the extensive and drawn-out public participation process, many of the facilities requested by the public were not integrated into the planning and design of the park. Environmentally, much of the building debris and waste was recycled on site and used to construct the park, therefore increasing sustainability, but the final product is a water-wasting landscape where vast lawns are prevalent, making the climate conditions insufferable when temperatures are high. Still, these issues, along with the acknowledgment of the park's limitations, do not detract from its appreciation in terms of design and aesthetics.

5. Conclusions and recommendations

Examining both the conceived space and lived space, the strong emphasis given by planners and residents alike to the image of the place and its' aesthetics has affected the development of the new studied park as a whole. Among the various competing factors that influence the design (i.e. social, environmental and planning), climate considerations were perceived as one parameter to address among many, but not as a leading factor that might influence significant decisions in the design process.

This case is one example out of many urban parks which have not incorporated climatic issues into planning ontology and methodology. Even if the vast lawns found in public parks, and specifically recently built beach-front parks in Tel Aviv, serve the general public, there are still measures which could be taken into consideration during the planning process in order to alleviate the impact on the environment and increase sustainability.

So how to explain this growing phenomenon of grass landscape in contemporary park planning, which seems to contradict accepted knowledge and governmental campaigns regarding environmentalism, climatic conditions and heat stress aggravation, decreased precipitation, severe water shortages and the lack of shade that contradict human comfort?

The answer to this is not definitive and we suggest an explanation that is tied to the contemporary decentralization of planning processes in the neo-liberal context. This context creates a competing situation on three interrelated aspects: (1) the actors, who decide on (2) the array and significance of parameters in the process of planning, and (3) an array, which in turn dictates the language of design. In other words, the array and interests of actors participating in the neo-liberal contemporary planning process causes a shift, the planner becomes a mediator among a vast array of social and political interests being advocated during a public participation process, a method which gives the power to the civil society and suspends scientific knowledge in favor of local wills. Thus, in the process of planning, environmental and climate issues are often perceived as neutral, obvious, or as barriers that attract significant parts of the budget and do not serve the immediate goals of community or political actors. Then, following the above, in a competition among social use, design, environmental and climate considerations, the first two parameters has gain higher priority. This influences the language of design and in the Jaffa case grass is used as a cheap solution that provides an immediate image. Grass is also a solution attached to cultivation worldwide, thus culturally is associated with beauty and aesthetics, crucial values in raising property rates and re-branding an area. As such, transforming the park into visual asset becomes an interest of both the municipality and designers who sees it as the most significant component in the success of such a project.

What can be done? How can climate considerations be better integrated into planning processes? What are the benefits of such integration? Clearly, in order to integrate the scientific knowledge to the 'making of place' and to avoid the random basis of considerations (if any at all), design codes are needed (Ben Josef, 2005). We need to recall that aesthetics are inextricably linked with ethics (i.e. the purpose for and the way which resources are being used) and as such, the only way to re-integrate scientific knowledge is in creating a standardized set of human comfort codes. Clear codes would include percentage of shading, percentage of area covered by water-intensive vegetation, etc. In an era of global warming and a shortage of water, these types of codes will not limit the scope of design creativity, but rather ground it in a feasible climatologist framework that at the end would support human comfort and would benefit the users. Furthermore, these codes would force municipalities to perform a better assessment of the economic feasibility of a landscape project.

Yet, the underlying significant question here is whether these codes or criteria benefit the society. Or is it a brutal intervention in the decision-making process that might limit the community's vision or will? Thus far, with the growing interest in the process of participation and inclusion in planning practice, studies have shown that the neo-liberal era is characterized with selective inclusion - people may gain more access to state institutions through local governments and the possibility of participation as well as social and political inclusion in institutions of the state. But, as noted by scholars (Holston, 1995; Alfasi, 2003; Roy, 2006; Watson, 2006; Miraftab, 2009), participation does not necessarily mean substantive inclusion or a just development (Fainstein, 2010). Thus, in the case of urban parks, considerations that would foster, as a primary goal, human comfort criteria would be a real step toward socially just development. In the long run, in the era of global warming, this set of codes would save resources and would benefit its users, by allowing them to enjoy the park all year long.

REFERENCES

Alfasi, N., 2003. Is Public Participation Making Urban Planning More Democratic? The Israeli Experience. Planning Theory and Practice 4 (2), 185-202.

Alpert, P., Ben-Gai, T., Baharad, A., Benjamini, Y., Yekutieli, D., Colacino, M., Diodato, L., Ramis, C., Homar, V., Romero, R., Michaelides, S., Manes, A., 2002. The paradoxical increase of Mediterranean extreme daily rainfall in spite of decrease in total values. Geophys. Res. Lett. 29, L1536.

Aronin, J.E., 1953. Climate and Architecture. Reinhold, New York.

Baldi, M., Dalu, G., Maracchi, G., Pasqui, M., Cesarone, F., 2006. Heat waves in the Mediterranean: A local feature or a large scale effect? Int. J. Clim. 26, 1477-1487.

Ben-Dor, E., Saaroni, H., 1997. Airborne video thermal radiometry as a tool for monitoring microscale structures of the urban heat island. Int. J. Rem. Sens. 18 (14), 3039-3053.

Ben-Joseph, E., 2005. The code of the city: standards and the hidden language of place making. MIT Press, Cambridge, Mass.

Beunen, R., Opdam, P., 2011. When landscape planning becomes landscape governance, what happens to the science? Landscape Urban Plan. 100, 324-326.

Bitan, A., Rubin, S., 1994. Climatic Atlas of Israel for Physical and Environmental Planning and Design. Ramot Publishing, Tel Aviv, Israel.

Dee, C., 2010. Form, utility and the aesthetics of thrift in landscape education. Landscape Urban Plan. 29, 1-10.

Eliasson, I., 2000. The use of climate knowledge in urban planning. Landscape Urban Plan. 48, 31-44.

Escobar, A., 1998. Whose Knowledge? Whose nature? Biodiversity, conservation, and the political ecology of social movements. J. Polit. Ecol. 5, 53–82.

Evans, M., 1980. Housing, Climate and Comfort. Architectural Press, London.

Evans, J.M., Schiller, S., 1996. Application of microclimate studies in town planning: a new capital city, an existing urban district and urban river front development. Atmosph. Environ. 30, 361-364.

Fainstein, S.S., 2010. The just city. Cornell University Press, Ithaca.

Fanger, P.O., 1970. Thermal comfort. Danish Technical Press: Copenhagen, Denmark.

Farr, D., (ed.) 2008. Sustainable urbanism: urban design with nature. Wiley, Hoboken, N.J.

Giorgi, F., Lionello, P., 2008. Climate change projections for the Mediterranean region. Glob. Planet. Change. 63, 90-104 doi: 10.1016/j.gloplacha.2007.09.005.

Givoni, B., 1976. Man Climate and Architecture. (2nd ed.), Applied Science Publishers, London, UK.

Givoni, B., 1991. Impact of planted areas on urban environmental quality: a review. Atmos. Environ. 25B (3), 289-299.

Givoni, B., 1998. Climate considerations in building and urban design. John Wiley & Sons, New York, NY.

Golany, G.S., 1996. Urban design morphology and thermal performance. Atmosph. Environ. 30 (3), 455-465

Harnik, P., 2010. Urban green: innovative parks for resurgent cities. Island Press, Washington, DC.

Hatuka, T., 2010. Violent Acts and Urban Space in Contemporary Tel Aviv: Revisioning Moments. University of Texas Press, Texas.

Holston, J., 1995. Spaces of Insurgent Citizenship. Planning Theory 13, 35-52.

IPCC, 2007. The physical science basis. Cambridge, UK and New York, NY, USA: Cambridge University Press. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Jendritzky, G., Menz, G., Schirmer, H., Schmidt-Kessen, W., 1990. Methodik zur Räumlichen Bewertung der Thermischen Komponente im Bioklima des Menschen, Bd. 114. Beiträge der Akademie für Raumforschung und Landesplanung: Hannover, Germany.

Jorgensen, A., 2011. Beyond the view: Future directions in landscape aesthetics research. Landscape Urban Plan. 100, 353-355.

Krichak S.O., Alpert, P., Bassat K, Kunin, P., 2007. The surface climatology of the eastern Mediterranean region obtained in a three-member ensemble climate change simulation experiment. Adv. GeoSci. 12, 67-80.

Lionello, P., Malanbotte-Rizzoli, P., Boscolo, R., 2006. Mediterranean climate variability. Developments in earth and environmental sciences, Vol. 4. Elsevier, Amsterdam, 325-372.

Lionello, P., Giorgi, F., 2007. Winter precipitation and cyclones in the Mediterranean region: future climate scenarios in a regional simulation. Adv. GeoSci. 12, 153-158.

Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M., Wanner, H., 2004. European seasonal and annual temperature variability, trends, and extremes since 1500. Science 303, 1499-1503 doi:10.1126/science.1093877.

McGregor, G.R., Nieuwolt, S., 1998. Tropical climatology. 2nd ed., John Wiley & Sons, Chichester.

McNie, E.C., 2007. Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. Environ. Sci. Policy 10, 17-38.

Meehl, G., Tebaldi, C., 2004. More intense, more frequent, and longer lasting heat waves in the 21st century. Science 305, 994-997.

Meyer, E.K., 2008. Sustaining beauty. The performance of appearance. A manifesto in three parts. J. Landscape Archit. 6-23.

Miller, L.B., 2009. Parks, plants, and people: beautifying the urban landscape. Norton, New York, NY.

Miraftab, F., 2009. Insurgent planning: Situating radical planning in the global south. Planning Theory, 8 (1), 32-50.

Oke, T.R., 1987. Boundary Layer Climates. 2nd edition. Methuen: New York; 435.

Oke, T.R., 2006. Towards better scientific communication in urban climate. Theor. Appl. Climatol. 84, 179–190 DOI: 10.1007/s00704-005-0153-0.

Park, H.S., 1987. City size and urban heat island intensity for Japanese and Korean cities. Geogr. Rev. Jpn. 60, 238-250.

Pearlmutter, D., 2007. Architecture and climate: The environmental continuum. Geocompass 1 (4), 752-778.

Potchter, O., Cohen, P., Bitan, A., 2006. Climatic behavior of various urban parks during hot and humid summer in the Mediterranean city of Tel Aviv, Israel. Int. J. Climatol. 26 (12), 1695-1711. DOI: 10.1002/joc.1330.

Raible, CC., Ziv B., Saaroni, H, Wild, M., 2010. Winter synoptic-scale variability over the Mediterranean Basin under future climate conditions as simulated by the ECHAM5. Clim. Dyn. 35, 473-488 DOI: 10.1007/s00382-009-0678-5.

Register, R., 2006. Ecocities: rebuilding cities in balance with nature. New Society Publishers, Gabriola, BC.

Roy, A., 2006. Praxis in the Time of Empire. Planning Theory 5 (1), 7-29.

Saaroni, H., Ben-Dor, E., Bitan A., Potchter, O., 2000. Spatial distribution and microscale characteristics of the urban heat island in Tel-Aviv, Israel. Landscape Urban Plan. 48, 1-18.

Saaroni, H., Ziv, B., Edelson, J., Alpert, P., 2003. Long-term variations in summer temperatures over the Eastern Mediterranean. Geoph. Res. Lett. 30 (18), 1946, doi: 10.1029/2003GL017742.

Spirn, A., W., 1998. The Language of Landscape. Yale University Press, New Haven.

Spronken-Smith R.A., Oke, T.R., 1998. The thermal regime of urban parks in two cities with different summer climates. Int. J. Remot. Sens., 19 (11), 2085-2104.

Walker, C., 2004. The public value of urban parks. Beyond Recreation, The Urban institute and Wallace foundation, http://www.urban.org/UploadedPDF/311011_urban_parks.pdf (accessed October 24, 2010).

Watson,V., 2006. Deep Difference: Diversity Planning and Ethics. Planning Theory 5 (1), 31-50.

Wheeler, S., 2004. Planning for sustainability: creating livable, equitable, and ecological communities. Routledge, New York, NY.

Wheeler, M. S., Beatley, T., (eds.) 2004. The sustainable urban development reader. Routledge, London; New York.

Willett, K.M., Gillett, N.P., Jones, P.D., Thorne, P.W., 2007. Attribution of observed surface humidity changes to human influence. Nature 449, 710-712.

Xoplaki, E., Gonzalez-Rouco, JF., Luterbacher, J., Wanner, H., 2003. Mediterranean summer air temperature variability and its connection to the large-scale atmospheric circulation and SSTs. Clim. Dyn. 20, 723-739 doi:10.1007/s00382-003-0304-x .

Ziv, B., Saaroni, H., Baharad, A., Yekutieli, D., Alpert, P., 2005. Indications for aggravation in summer heat conditions over the Mediterranean Basin. Geophys. Res. Letters. 32 (12), L12706 doi: 10.1029/2005GL022796.

Ziv, B., Saaroni, H., 2011. The contribution of moisture to heat stress in a period of global warming: the case of the Mediterranean. Clim. Chang. 104 (2), 305-315 DOI: 10.1007/s10584-009-9710-3.

Cooling the Public Realm: Climate-Resilient Urban Design

Jeffrey Raven

Figure 1: Climate-Resilient Urban Design for Proposed Waterfront District, Thanh Hoa City by 2020, Vietnam, Raven-LBG (2008).

Shaping Resilient Cities for the 21st Century by Adapting Urban Design to Climate Change

Global climate change has rendered traditional urban design processes obsolete. A new paradigm is required in order to develop resilient cities able to adapt and thrive in changing global conditions, meet the requirements of carbon-reduction and other environmental measures, and sustain compact urban populations by providing necessary and desirable amenities for urban residents. The scope and speed of current changes demands that urbanists define compelling visions and integrated design measures for shaping resilient cities. From energy and transportation to water and green infrastructure, urbanists can shape these systems to shrink our ecological footprint, configure resilient urban form and adapt our cities to climate change.

As global temperatures rise, a central challenge will be to create compact, cool urban settlements. This requires informed knowledge of climate-resilient urban design, drawing from fields such as urban climatology and sustainable design. However, despite considerable technical knowledge within these fields, climate-resilient urban design has not yet emerged as a major consideration in standard urban design practice (Fig. 2, 3, 4).

Sustainable Designation Systems Sustainable Designation Systems, or sustainability rating systems, are currently in development in the United States at the neighborhood and district scales, with the aim of developing sustainable communities throughout the country. This paper suggests morphological and climate-resilient urban design measures for the rating systems. The term morphological here describes the simplified three-dimensional form of the built environment and the spaces it creates. These

The original publication of this author's version is in Resilient Cities (2011) and available at www.springerlink.com

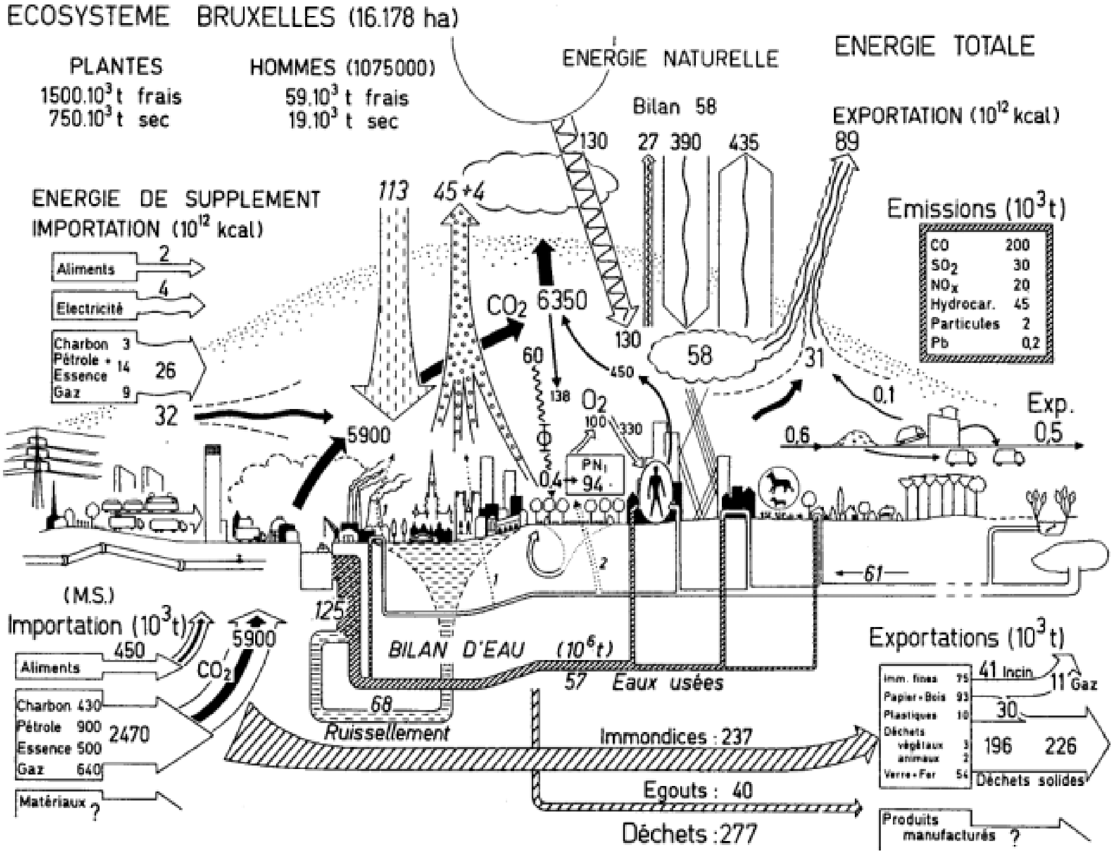


Figure 2: Inputs and outputs-- a systemic approach to an urban context across sectors and scales, Duvigneaud, P. et Denayer-de Smet, S. (eds.) (1975) L' Ecosystème Urbain.

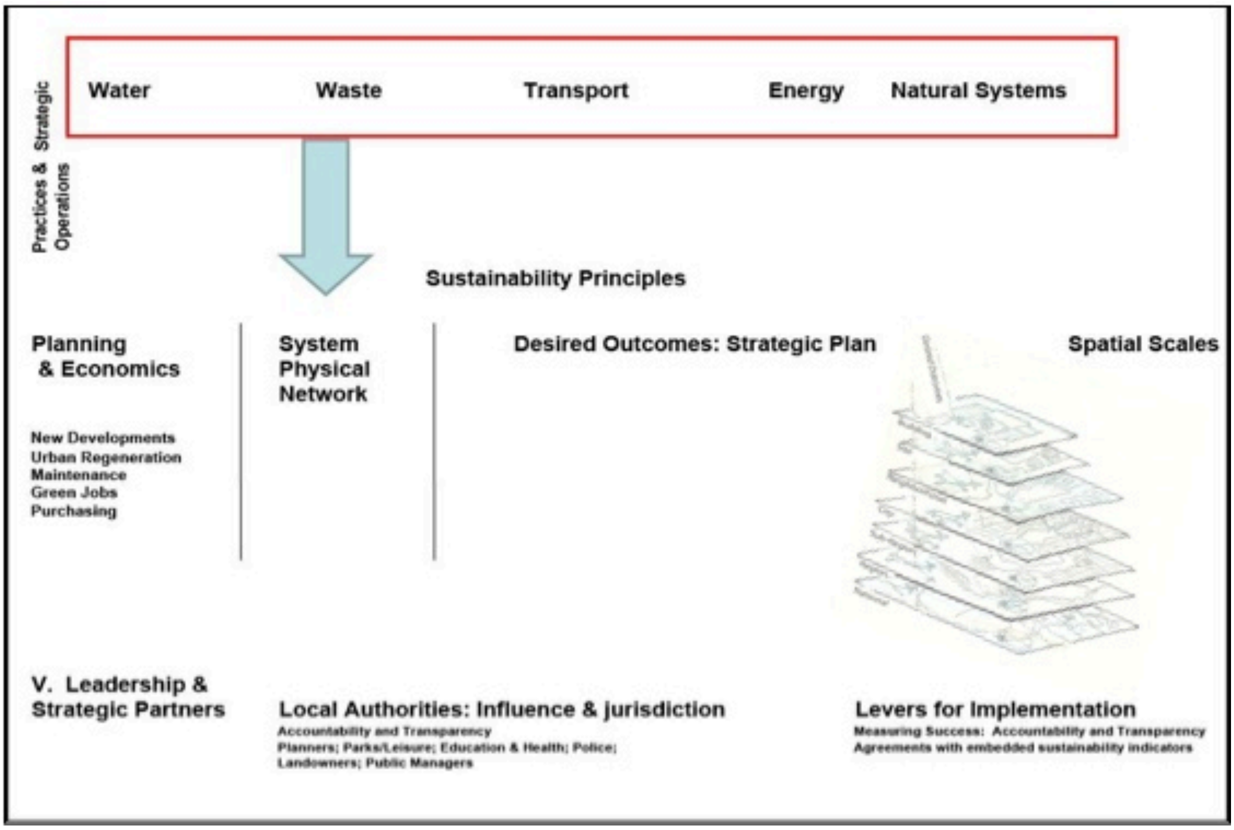


Figure 3: An integrated sustainable planning process, Adapted from CABE, UK

climate-resilient urban design measures should be adapted to sustainability rating systems with pilot testing evaluation criteria for measuring benefits.

The prototype sustainability rating systems STAR Community Index (STAR), US Green Building Council's (USGBC) LEED for Neighborhood Development (LEED ND) and the international Clinton Climate Initiative's Climate Positive Development Program (Climate+) provide opportunities for developing climate-resilient urban design prescriptive measures and performance standards for broad implementation (Fig. 5).

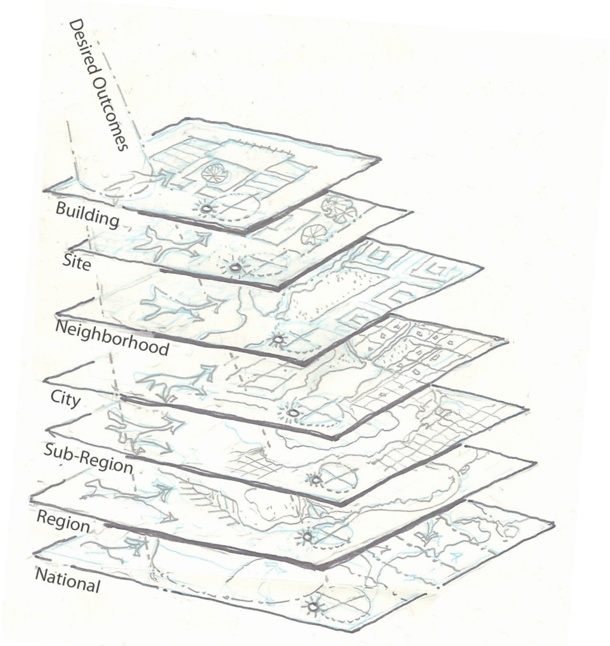


Figure 4: Implementing key climate-resilient urban design desired outcomes across varied spatial scales, Raven (2008).

Climate-resilient urban design across all phases:

- *A handful of systems play a central role in the life of urban districts including Energy, Transportation, Waste, Water, and Green Infrastructure/Natural Systems.*
- *These systems are part of a physical network.*
- *Physical networks are within the jurisdiction and responsibility of key stakeholders.*
- *Once sustainability principles have been defined by stakeholders, an integrated planning process should be undertaken.*
- *"Desired Outcomes" result from filtering original sustainability principles through the integrated planning process unique to a context and spatial scale (Fig. 4, right).*
- *Transparency and Accountability: Political, social and economic forces shape the implementation of the "desired outcomes".*
- *Practices and Strategic Operations: Implementing sustainability strategies at a project level.*

Figure 5: STAR Logo for STAR Community Index, ICLEI (Local Governments for Sustainability) (2008). Logos: USGBC LEED ND and Clinton Climate Initiative's Climate Positive Program.

Municipal governments are the targets of the STAR Community Index, with sustainability broadly defined to include equity, economy and environment. Its policy-driven mandate ranges from urban design to local economy to social justice (ICLEI 2009). The primary target audience of LEED ND is the building industry, including property developers and architects. Its project-driven mandate ranges from storm water capture to traffic-calming and urban density incentives (USGBC 2009). The primary targets of the Climate Positive Development program are public-private partnerships required for large international developments. Its project-driven mandate hinges on reducing the amount of on-site CO2 emissions to below zero (Clinton Climate Initiative 2009). These rating systems all aspire to become gold standards for their target audience and provide robust metrics with which to measure success. They are currently in various phases of development, and it remains to be seen if the final versions of these systems will overcome considerable challenges to directly address climate-resilient urban design strategies for climate adaptation and test pilot projects for future resiliency.

Given its ambitious scope, varied scales and geographic diversity, the STAR Community Index may be the most challenging of the sustainability rating systems with which to measure success (Fig. 6). The Measuring sustainability briefing (ICLEI 2009) describes how USGBC’s LEED rating systems provide a precedent for measuring progress and how indicators of performance can play a role in the STAR Community Index. The STAR Community Index is a sustainability framework conceptualized as a designation type of rating system which relies on prescriptive measures and performance standards to set achievement levels of the attainment of points or credits within the system (ICLEI 2009).

A climate-resilient urban design strategy requires expanding traditional place-making urban design qualities to include principles of sustainable design such as resilience, comfort, resource efficiency, and biotic support (Fig. 7). Applying these principles to sustainability rating systems helps to identify and strengthen prescriptive measures and performance standards. These will address threats posed by climate change on the public realm – by focusing on public realm vulnerabilities and adaptive opportunities through climate-resilient goals, measures and performance indicators. An

Figure 6: Cities are uniquely complex due to scale, climate, socio-economics, overlapping urban systems and regional form. The development of sustainable cities by urban planning practioners tends to focus on broad policy objectives, as aillustrated by the Egan Wheel, Eganwheel www.microcoaches.co.uk (2009)

<table>
<tr><th colspan="2">Traditional Urban Design “Choice-Supporting” Paradigm Compared to “Sustainable” Urban Design</th></tr>
<tr><td><i>Traditional Urban Design</i></td><td><i>Sustainable Urban Design</i></td></tr>
<tr><td>Permeability – connectivity</td><td>Resilience – Adaptive</td></tr>
<tr><td>Vitality – Interactions</td><td>Comfort - Environment Permeability</td></tr>
<tr><td>Variety – Options</td><td>Resource Efficiency - Demand, Synergy, Re-Use</td></tr>
<tr><td>Legibility – Understandable</td><td>Biotic Support - Environmental Diversity</td></tr>
<tr><td></td><td>Health - Pathological Prevention</td></tr>
</table>

Figure 7: Broadening traditional place-making urban design qualities with “sustainability supporting” qualities, Odoleye et al., (2008).

additional challenge will be to create the tools necessary to assess conditions of urban environments at city block or neighborhood scale. In present practice there is a lack of clarity concerning the impact of regional decisions on neighborhood or individual scales and vice versa. The need for transparent planning processes between local and regional scales and clear accountability are two additional aspects that should be considered in the context of efficient rating systems.

Climate-resilient public realm measures would strengthen community adaptability to climate change and mitigate the urban heat island effect through the creation of systemic, interconnected and protective micro-climates within the public realm intended to reduce energy loads, produce cleaner air and enhance civic life. Prescriptive measures and performance standards for a climate-resilient public realm would address systemic impacts on the public realm, including urban ventilation, green infrastructure, and solar design. Urban surface reflectivity (albedo), sky visibility (sky-view factor) and anthropogenic (user) emissions remain key elements within these categories.

Urban Ventilation and Green Infrastructure

Urban ventilation and green infrastructure strategies capitalize on prevailing breezes to improve air quality while mitigating the urban heat island effect. Wind affects temperature, rates of evaporative cooling and plant transpiration and is

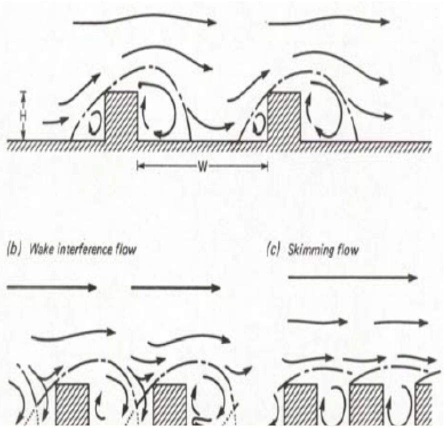


Figure 8: Wind flow associated with different urban geometry and surface "roughness", Oke (1987)

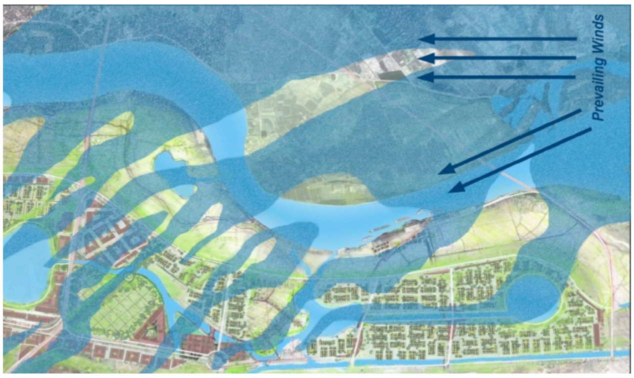


Figure 9: Waterfront district configured for maximum urban porosity, to capture summer breezes, Raven-LBG (2008).

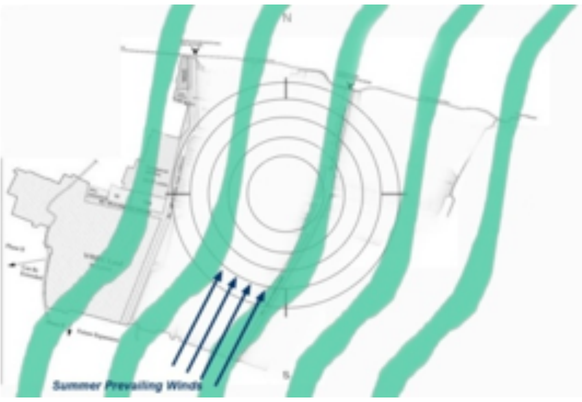


Figure 10: Site plan configured for maximum urban porosity, to capture summer breezes, Raven (2010)

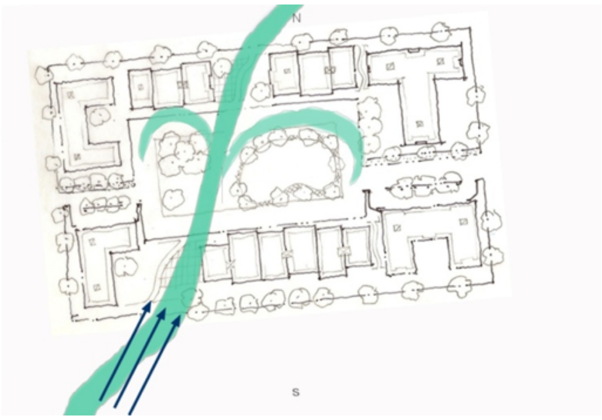


Figure 11: Configuring vegetation and buildings to direct desirable summer air flows; cross-ventilation through dual-aspect buildings, Raven (2010).

thus an important factor in implementing district-wide passive cooling strategies at a micro-climatic level. Urban morphology is responsible for varying the surface roughness (Figure 8) and porosity of the city that impacts airflows effectiveness in passive cooling and reducing energy loads in the built environment (Figures 9-12).

Summer breezes across parks, green roofs and water bodies can accentuate its cooling effect, and alignment of street canyons can be used for external cooling but also can be effective for passive cooling in buildings. For example, Masdar's streets are mainly used for pedestrian circulation, fresh air distribution, and microclimate protection. Its two green park bands that stretch throughout the city are oriented toward the sea breeze and the cool night winds (See figure 15).

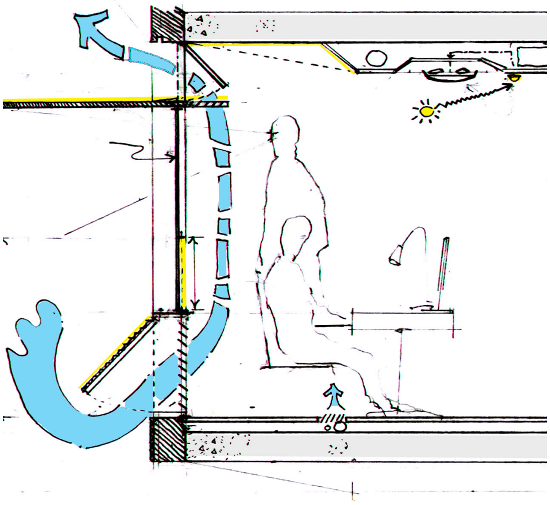


Figure 12: Ensuring opportunities for cross-ventilation and solar access, including laying out dual-aspect living and working quarters, Raven (2008)

Figure 13 and 14: Green and blue fingers - Linear parks and urban forests: Contiguous green corridors, canals and open space networks: conceiving stormwater retention as urban design amenities: enhanced connectivity and transportation, Thanh Hoa City by 2020, Raven-LBG (2008)

Figure 15: City model detail - "Green fingers" through dense, energy-efficient, pedestrian-friendly neighborhoods of cool streets, urban squares lower building cooling loads. Masdar carbon-neutral development, Abu Dhabi, Fosters + Partners.

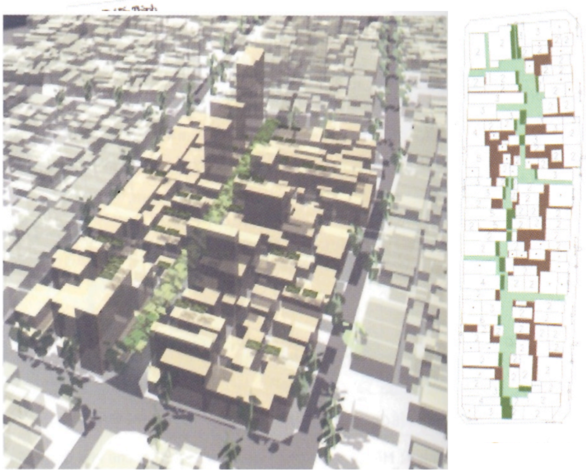


Figure 16: Retrofitting an urban network of many small green spaces or "urban forests" through Hanoi, l'Université de Laval (2006)

The original publication of this author's version is in Resilient Cities (2011) and available at www.springerlink.com

Figure 17: The viability of passive ventilation strategies is increased through adjoining low-impact transportation systems, illustrated in Vauban, Germany, http://graphics8.nytimes.com/images/blogs/greenic/vauban.jpeg. (2009)

The Thanh Hoa City by 2020 plan in northern Vietnam uses similar strategies in a tropical climate, where linear parks along canals align with prevailing summer winds to create fresh air corridors through the city grid (Fig. 9, 13, 14). The viability of passive ventilation strategies hinges on considerations across other urban sectors, from transportation to anthropogenic heat sources from day-to-day activities of city inhabitants (Fig. 17). In Masdar, streets continue serving city-wide circulation, but phasing out internal combustion engines from city streets in favor of electric vehicles removes important air quality and noise challenges (Schuler, 2009).

Solar Design and Thermal Comfort

Solar design is an effective passive strategy to increase comfort and reduce energy loads at a neighborhood scale. The urban canyon, which is a simplified rectangular vertical profile of infinite length, has been widely adopted in urban climatology as the basic structural unit for describing a typical urban open space (Ali-Toudert et al., 2005, p.2). For street canyon geometry, one of the most useful measures of the urban terrain is the “sky view factor” (SVF) (Figs. 18, 19) which expresses the relationship between a surface and sky, introducing the concept of opening or closing the space.

In addition to vertical profile, the orientation of the urban canyon has a decisive impact on the human thermal sensation at street level. Patterns of urban settlement based on climate, topography and geology highlight the important relationship between passive climate-resilient strategies derived from urban form and a comfortable public realm. For example, the diagonal grid with 45-degree diagonal orientation off cardinal points leaves every street with some direct sunlight during winter months, and some shadow during most of the summer day, although it is important to balance preferred street configuration against optimal building configuration (Fig. 20).

Figure 18: Fish eye image used for measuring sky view factor (SVF), http://www.gvc2.gu.se/ngeo/urban/Activities/svf.htm (2009).

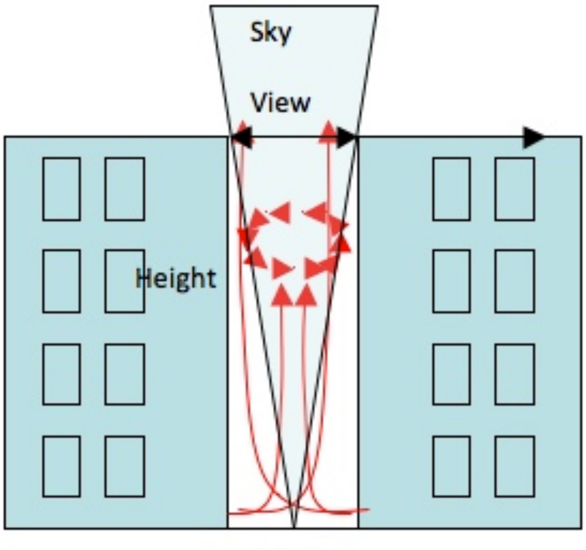


Figure 19: Cross-section through a symmetrical urban canyon. “Height” is the building height and urban canopy height, “Width” is the separation between buildings, “Sky View Factor” is defined as the proportion of the viewing hemisphere occupied by the sky. Red arrows illustrate heat trapped within urban canyon or reflected to the sky, depending on urban geometry and surface materials.

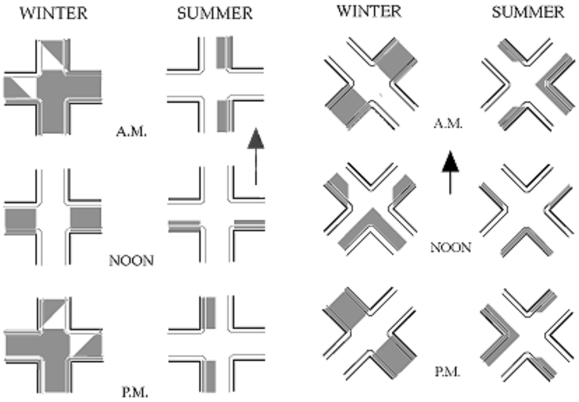


Figure 20: “Jeffersonian” grid (left) that runs along north-south cardinal points; “Spanish” grid (right) with 45-degree diagonal orientation off cardinal points, Walter et.al. (1992).

There is currently no single “silver bullet” climate-resilient urban design tool that has been developed across spatial scales and sectors. Researchers have determined that more than a single tool will be necessary. This Iterative, Spatial, Scalable, Synthetic, Multi-issue, Accessible, and Economical “suite” of tools, would share a common engine of methodological concepts and standards (Miller et al., 2008, p.23). This suite of tools will be required to provide practical guidelines across systems and spatial scales for urban design practitioners, and generate scenarios based on alternative urban forms.

At a regional scale, the quantity of radiant heat energy emitted by low-density, largely single-family districts can be determined with the aid of remotely sensed thermal data collected by the National Aeronautical and Space Administration (NASA) (Fig. 21) (Stone et al., p.3). Comparing low-density with higher density “compact” districts in Atlanta, this research has argued for a nuanced analysis of the relationship between land use density, urban morphology and the urban heat island effect. The research argues that thermal efficiency (based on thermal emissions) per single-family plot of land actually increased in higher-density, more compact districts (Figs. 3-9, 3-10, 3-11, 3-12). This finding directly challenges common assumptions that higher residential

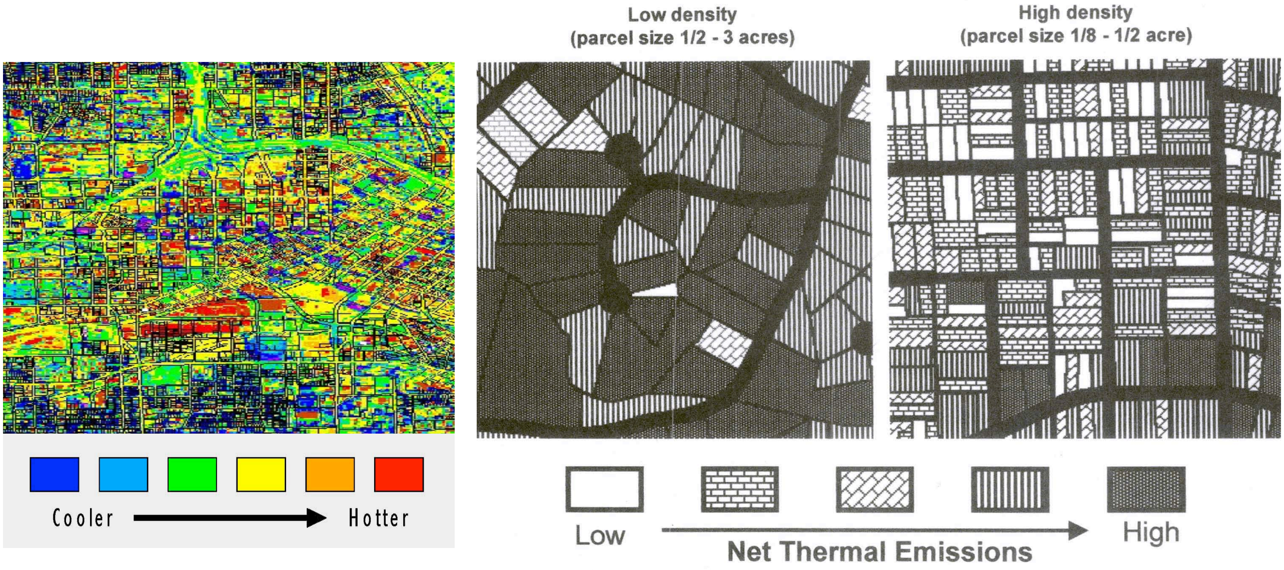


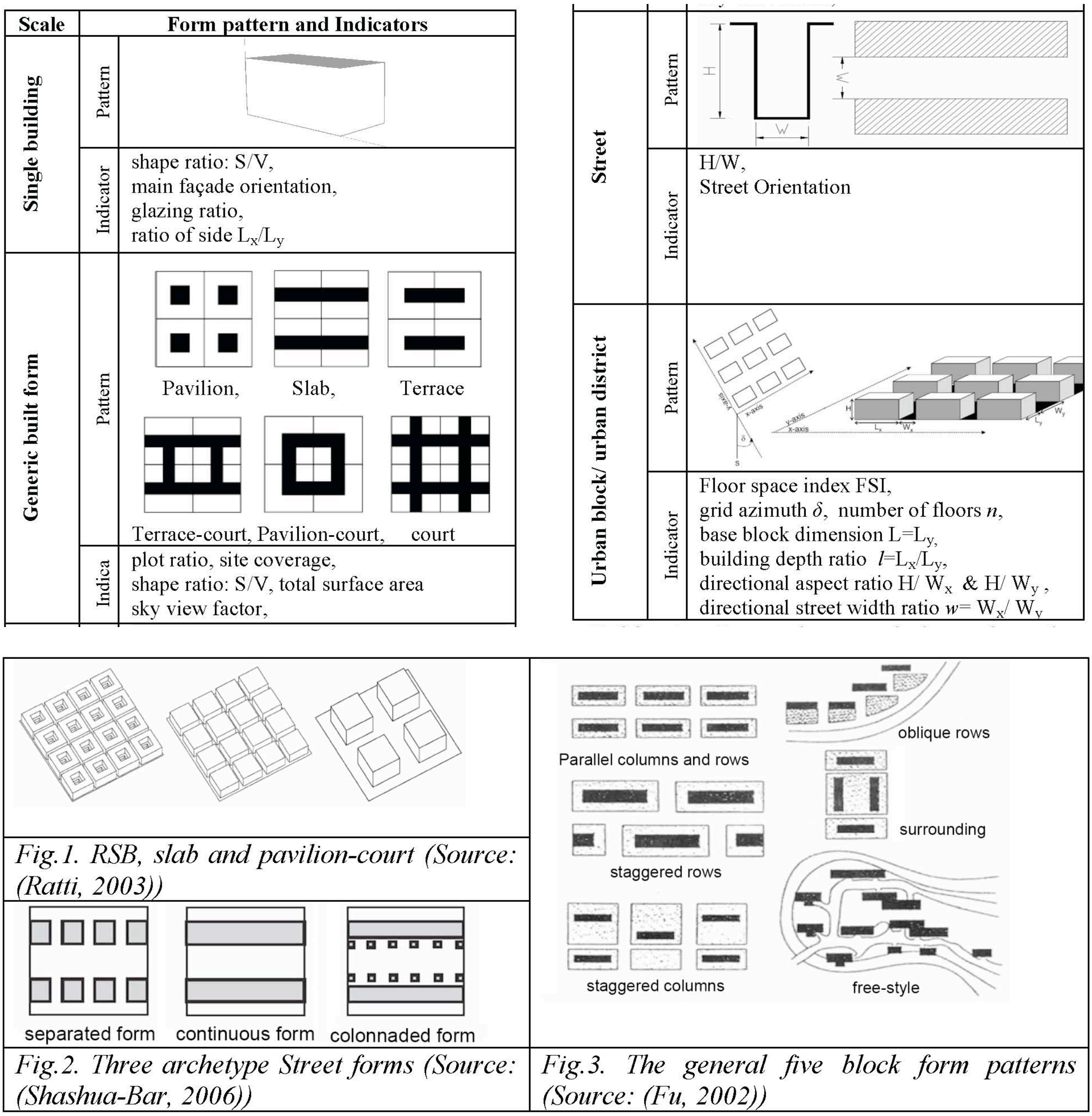
Figure 21: At a regional/district scale, parcel-based surface warming showing thermal emissions efficiency based on morphological indicators, http://www.gcp-urcm.org/files/A20060904/theme4/stone.pdf (2006).

densities are less thermally efficient than lower residential densities.

In a Martin Centre study at the University of Cambridge, archetypal generic built forms from an urban block arrangement derived from a simplified urban fabric were linked to solar exposure (Ratti 2003). These archetypal, generic urban form patterns could be characterized to form the basis for applying morphological indicators (Figure 25). Those, in turn would be the basis for prescriptive measures and performance standards.

Figure 23: New suburban sprawl: Low-density development, low-efficiency thermal emissions per parcel, http://www.re-nest.com/uimages/re-nest/5-11-2009suburb.jpg (2009).

Figure 24: Higher density residential development, mature tree canopy layer, higher-efficiency thermal emissions per parcel, http://www.davidwallphoto.com (2009).



Scale		Form pattern and Indicators
Single building	Pattern	
	Indicator	shape ratio: S/V, main façade orientation, glazing ratio, ratio of side L_x/L_y
Generic built form	Pattern	Pavilion, Slab, Terrace Terrace-court, Pavilion-court, court
	Indica	plot ratio, site coverage, shape ratio: S/V, total surface area sky view factor,

Street	Pattern	
	Indicator	H/W, Street Orientation
Urban block/ urban district	Pattern	
	Indicator	Floor space index FSI, grid azimuth δ, number of floors n, base block dimension $L=L_y$, building depth ratio $l=L_x/L_y$, directional aspect ratio H/W_x & H/W_y, directional street width ratio $w=W_x/W_y$

Fig.1. RSB, slab and pavilion-court (Source: (Ratti, 2003))

Fig.2. Three archetype Street forms (Source: (Shashua-Bar, 2006))

Fig.3. The general five block form patterns (Source: (Fu, 2002))

Figure 25: An elementary framework composed of basic urban form patterns and morphological indicators should be developed representing different spatial scales, Bouyer (2009).

For example, it is possible to characterize a limited number of generic North American neighborhood configurations and the related district configurations into which they assemble. Once characterized, the inherent or potential climate impacts from this small palette of neighborhood types and limited set of inputs could be assessed, thereby avoiding the necessity of assigning attributes on a much smaller parcel by parcel scale. Once assembled, these patterns could then be used to generate regional scenarios. With this method, it would be possible to develop a tool that would simplify data input, analyze scenarios quickly and cheaply, and potentially function in real-time in collaborative, public processes (Miller et al. 2008).

If height information is included at a more detailed level, a three-dimensional illustration such as a Digital Elevation Model (DEM) could be developed, which is an image where each pixel of the figure-ground map has a grey-level proportional to the urban surface (Fig. 26) (Ratti et al., 2003). By correlating urban form and various aspects of environmental performance with respect to the solar and wind environments and energy consumption, an evaluation of the environmental impact of alternative urban forms can be accomplished without the need for elaborate models. Sky view factor (SVF), the proportion of sky visible in a 180 degree field of view, or the aspect ratio, the height of the street canyon divided by its width, are both readily quantifiable measures of urban terrain (Smith et al., 2008, p. 2). By applying three-dimensional urban textures, a suite of tools can draw connections at a simplified level between urban form and microclimate characteristics (Steemers et al., 2004, p.17).

More sophisticated software is increasingly available for simulating sunshine, lighting and thermal radiation to determine micro-climate impacts of three-dimensional urban form. These tools evaluate sunshine/shadow; solar energy, solar reflections, luminous transmission and thermal radiation as factors that shape the comfort profile of the public realm (Fig. 27). urban block arrangement derived from a simplified urban fabric were linked to solar exposure (Ratti 2003). These archetypal, generic urban form patterns could be characterized to form the basis for applying morphological indicators (Figure 25). Those, in turn would be the basis for prescriptive measures and performance standards.

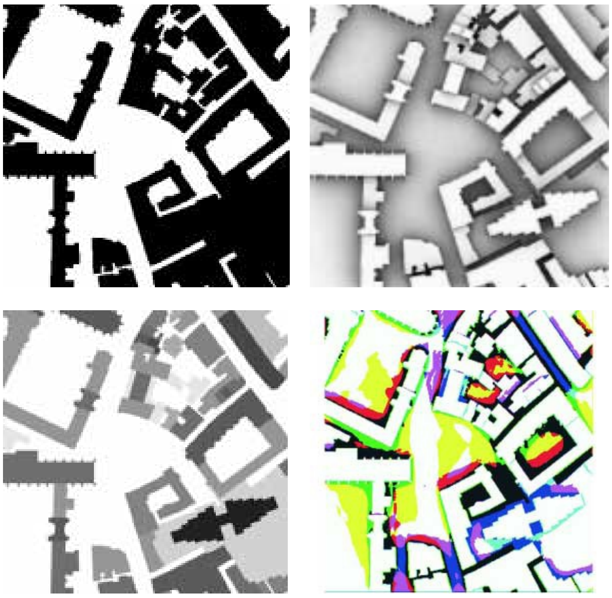


Figure 26: illustrating selection from suite of tools, determining comfort or "desirability" factor in the public realm, based upon individual microclimatic variables (2004). Clockwise: Figure-ground map; Sky-view factor (SVF) map; Open space diversity profile; Digital elevation model (DEM), Steemers, et al. (2004)

For example, it is possible to characterize a limited number of generic North American neighborhood configurations and the related district configurations into which they assemble. Once characterized, the inherent or potential climate impacts from this small palette of neighborhood types and limited set of inputs could be assessed, thereby avoiding the necessity of assigning attributes on a much smaller parcel by parcel scale. Once assembled, these patterns could then be used to generate regional scenarios. With this method, it would be possible to develop a tool that would simplify data input, analyze scenarios quickly and cheaply, and potentially function in real-time in collaborative, public processes (Miller et al. 2008).

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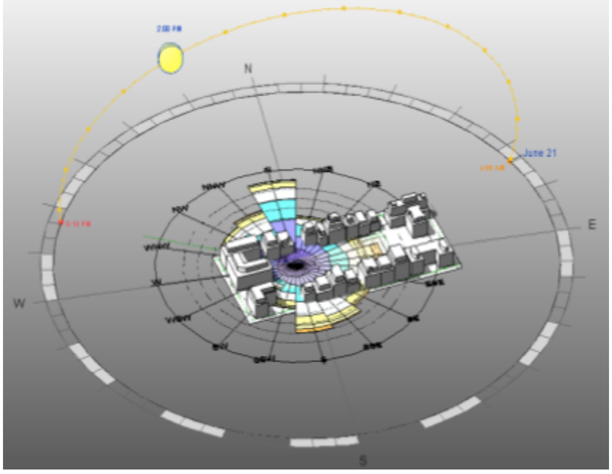

Figure 27: Solar, wind and morphological study, Raven (2010)

environmental impact of alternative urban forms can be accomplished without the need for elaborate models. Sky view factor (SVF), the proportion of sky visible in a 180 degree field of view, or the aspect ratio, the height of the street canyon divided by its width, are both readily quantifiable measures of urban terrain (Smith et al., 2008, p. 2). By applying three-dimensional urban textures, a suite of tools can draw connections at a simplified level between urban form and microclimate characteristics (Steemers et al., 2004, p.17).

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The Pilot Test methodology for the Sustainable Designation Systems should measure the success of these climate-resilient urban design strategies across different spatial scales, geographies and climate. The development of Sustainable Designation Systems, such as STAR, LEED ND, and the Climate Positive Development Program, should involve a sequence of phases, each with feedback loops to test the system's logic and validity. As these rating systems become fully operational, it will be possible to model and test the micro-climate indicators of an actual climate-resilient urban design pilot goal. This paper suggests a prototype framework and methodology for the Pilot Phase so as to evaluate the future results.

The quantitative climate-resilient assessment of a rating system pilot case-study would include the use of two sets of archetypal standard urban

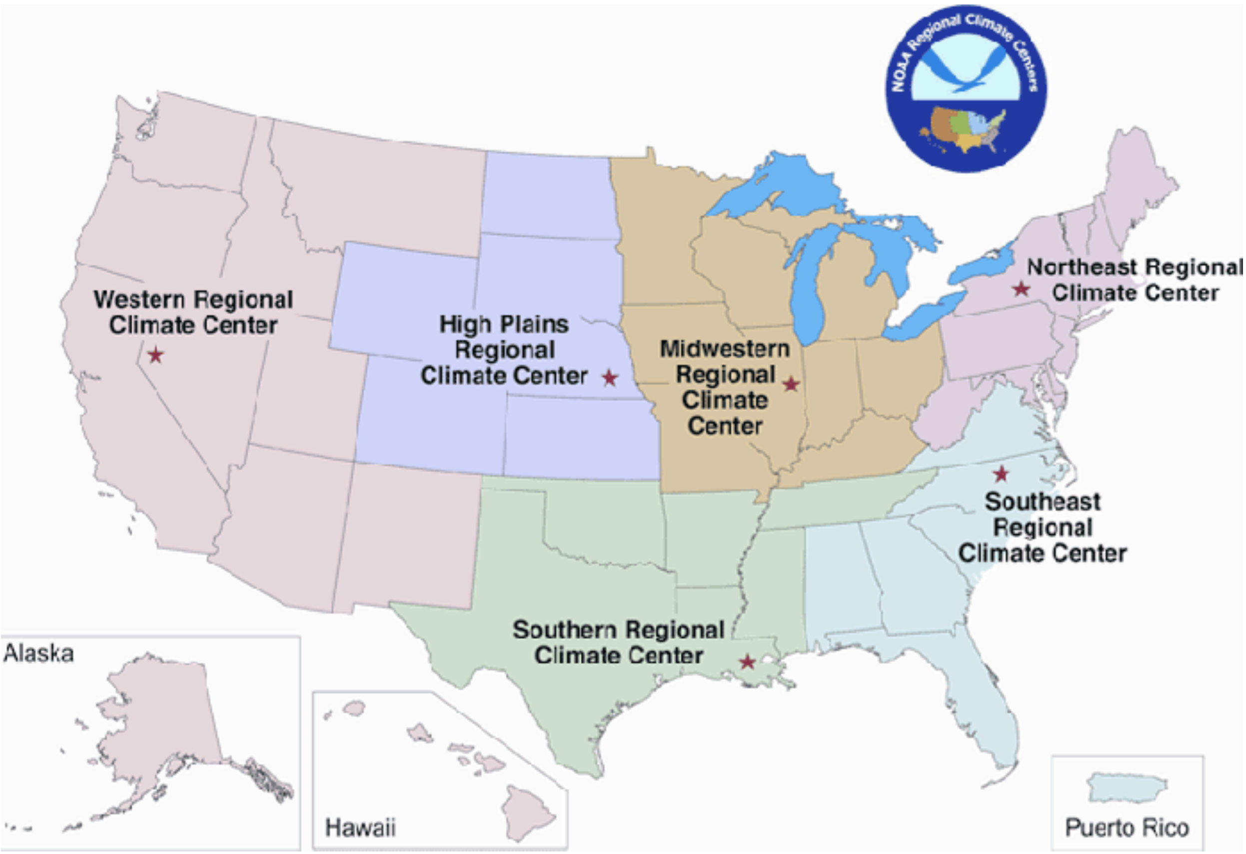

Figure 28: For project verification in the USA, nine Pilot Communities should be selected based on geographic variation, representing each of nine US National Climate Data Center (NCDC) regions, http://lwf.ncdc.noaa.gov/oa/climate/regionalclimatecenters.html (2009).

patterns for study, targeted to a varied group of city types, climates and geographies. This could range from a high-density urban core to an inner-ring suburb to an edge city, from sub-tropical to desert. One set for each location would be a “baseline” conventional urban design pattern. The second set would represent “best practice” urban form suitable to local conditions. Built in the same locations as the archetypal models, actual sustainable rating system-accredited Pilot Community projects would be evaluated in real time against these two sets of benchmarks.

The three sets, baseline model, best practices model and actual Pilot Community project would be tested based on climate-resilient urban design indicators discussed earlier in this work. The suite of tools would evaluate albedo, sky view factor, solar design and urban ventilation. Anthropogenic heat sources from city inhabitants should also be factored in. For lower-density, uniform morphologies, radiant heat energy could be modeled to simulate the thermal efficiency study of residential districts described earlier. For more localized urban spaces, the three-dimensional micro-climate analysis would begin to suggest unique diversity and desirability profiles.

To account for climate change, these indicators should assume at least two plausible future climate conditions: increasing temperature (20 and 90 years time period) and increasing intensity of heat wave events, based on weather data (Pyke et al. 2007). A modest change scenario would be equivalent to extrapolating the observed trend for 20 years (a typical time horizon for planning). A longer-term change scenario would be equivalent to extrapolating the observed trend 90 years into the future (i.e., end of the 21st century, a benchmark often used in climate change analyses). These changes should be applied to a ten-year historical daily climate record (1996-2005) from each of the nine representative cities (Pyke et al. 2007). For the United States, nine Pilot Communities could be selected based on geographic variation, representing each of nine US National Climate Data Center (NCDC) regions. (Fig. 28).

The climate adaptive performance of the Pilot Communities should compare morphological urban design indicators against conventional baseline condition and best practice models. The important question in evaluating the results would be: do the pilot tests accurately predict performance? It would be important to create effective feedback loops so that this information continues to shape the rating systems.

A prototype testing protocol similar to the one suggested here could provide transparency and accountability to the decision-making process. As these rating systems continue through the prototype phases, developing transparent testing protocols backed by clear accountability will be the next stage of the work.

Climate mandates from federal, state and provincial governments are now impacting the practice of urban design as cities face mandates to bring their transportation, zoning, building codes and economic development policies into alignment with required greenhouse gas reduction goals and reduce vulnerabilities from that part of climate change that is already unavoidable. This development has signaled a shift in focus in urban design policies from greenhouse gas emission mitigation strategies to risk analysis, adaptation and resilience.

The half-century design life for the built environment means that current urbanists and policymakers must create resilient cities within paradigms appropriate for future climates. Under changing conditions, solutions requiring fewer resources, rather than more, are likely to be robust, which is why reducing energy demand through climate-resilient strategies is such an important first step. This approach can reap significant benefits in the long term, including economic savings and risk reduction through reduced energy consumption, while improving the ability of communities to thrive despite heavy impacts related to climate change.

Forward-thinking cities should exploit climate-resilient urban design measures in order to future-proof their built environments in expectation of continuing climate change. Passive urban design strategies to lock in long-term resilience and sustainability should be promoted; this would reduce reliance on applied technologies that may require expensive maintenance or quickly become obsolete.

REFERENCES

Ali-Toudert, F., Mayer, H. (2005), "Effects of Street Design on Outdoor Thermal Comfort", Meteorological Institute, University of Freiburg, Werderring 10, D-79085, Freiburg.

Bouyer, J., Musy, M., Huang, Y., Athamena, K. (2009) "Mitigating Urban Heat Island Effect by Urban Design: Forms and Materials", Fifth Urban Research Symposium, Cities and Climate Change: Responding to an Urgent Agenda, Marseille.

Brophy, V., O'Dowd, C., Bannon, R., Goulding, J., Lewis, J.O. (2000) Sustainable Urban Design, Energy Research Group, University College Dublin, Dublin, Ireland, Energie Publications, European Commission.

Comprendre L'Habitat de Ha Noi (2006) Les Presses de l'Université de Laval, Québec.

ENVI-met (2009) http://www.envi-met.com.

"Global Change Impacts in the United States" (2009) US Global Change Research Program, Cambridge University Press.

Knowles, R. (1992) "Solar Design", in Walter, B., Arkin, L., Crenshaw, R. (ed.) Sustainable Cities: Concepts and Strategies for Eco-City Development, Eco-Home Media.

LEED for Neighborhood Development (2009) U.S. Green Building Council.

Physical Development Plan for the State of Qatar (1998) Ministry of Municipal Affairs and Agriculture Planning Department.

Thanh Hoa City by 2020 (2008) Presented to the Thanh Hoa People's Committee, THC Planning Institute, The Louis Berger Group, Socialist Republic of Vietnam, 2008.

"Measuring Sustainability Briefing" (2009) STAR Community Index, ICLEI-Local Governments for Sustainability, USA.

Miller, N., Cavens, D., Condon, P., Kellett, N., Carbonell, A. (2008) "Policy, Urban Form and Tools for Measuring and Managing Greenhouse Gas Emissions: The North American Problem", Climate Change and Urban Design: The Third Annual Congress of the Council for European Urbanism, Oslo.

Odeleye, D., Maguire, M. (2008) "Walking the Talk? Climate Change & UK Spatial Design Policy", Climate Change and Urban Design: The Third Annual Congress of the Council for European Urbanism, Oslo.

Oke, T.R. (1988) "Street Design and Urban Canopy Layer Climate", Energy and Buildings 11, 103-113.

Pyke, C., Jonhson, T., Scharfenberg, J., Groth, P., Freed, R., Schroeer, W., Main, E. (2007) "Adapting to Climate Change through Neighborhood Design", CTG Energetics, Inc., Ivine, California.

Ratti, C., Raydan, D., Steemers, K. (2003) "Building Form and Environmental Performance: Archetypes, Analysis and an Arid Climate", Energy and Buildings 35, 49-59, Elsevier Science B.V.

Schuler, M. (2009) "The Masdar Development – Showcase with Global Effect", Urban Futures 2030, Visionen künftigen Städtebaus und urbaner Lebensweisen, Band 5 der Reihe Ökologie, Herausgegeben von der Heinrich-Böll-Stiftung, http://www.boell.de/downloads/Urban-Future-i.pdf.

Sheppard, S., Pond, E., Campbell, C. (2008) "Low-Carbon, Attractive, Resilient Communities: New Imperatives for Sustainable Retrofitting of Existing Neighborhoods", Climate Change and Urban Design: The Third Annual Congress of the Council for European Urbanism, Oslo.

Solene (2009) Software for Simulating Sunshine, Lighting and Thermal Radiation, http://www.cerma.archi.fr/CERMA/Expertise/CERMA/Expertise/solene/soleneanglais/document_view.

Smith, C., Levermore, G. (2008) "Designing Urban Spaces and Buildings to Improve Sustainability and Quality of Life in a Warmer World", Energy Policy, doi:10.1016/j.enpol.2008.09.011, Elsevier Ltd., United Kingdom.

Steemers, K., Ramos, M., Sinou, M. (2004) "Urban Morphology", The Martin Center for Architectural and Urban Studies, University of Cambridge, UK, Designing Open Spaces in the Urban Environment: a Bioclimatic Approach, Rediscovering the Urban Realm and Open Spaces

(RUROS) and Centre for Renewable Energy Sources (C.R.E.S), Attiki, Greece.

Stone, B., Rodgers, M. (2001) “Urban Form and Thermal Efficiency: How the Design of Cities Influences the Urban Heat Island Effect”, APA Journal, Spring 2001, Vol.67, No.2.

Stone, B. (2008) “Urban Heat Islands Webcast”, US Environmental Protection Agency (EPA), httpepa.govheatislandresourceswebcasts.htm#recent.

“System Requirements Document (draft)” (2009) Climate Positive Development Program, Clinton Climate Initiative.

Thomas, R. (2003) Sustainable Urban Design: An Environmental Approach, Max Fordhham LLP, London: Spon Press

United States Environmental Protection Agency (2009) “Reducing Urban Heat Islands: Compendium of Strategies”, US EPA Office of Atmospheric Programs, Climate Protection Partnership Division, http://www.epa.gov/hiri/resources/pdf/GreenRoofsCompendium.pdf.

Watson, D., Plattus, A., Shibley, R. (eds.) (2003) Time-Saver Standards for Urban Design, McGraw-Hill.

Other Sources Consulted

Akbari, H. (2009) Heat Island Group, Lawrence Berkeley Labs, http://eetd.lbl.gov/HeatIsland/.

Bloomberg, M. PlaNYC Progress Report 2009, The City of New York, Mayor Michael R. Bloomberg, Mayor's Office of Long-Term Planning and Sustainability, City Hall, New York, NY. www.nyc.gov/planyc2030.

Brown, P (ed) (2009) CABE: Hallmarks of a Sustainable City, Commission for Architecture and the Built Environment, http://www.cabe.org.uk/files/hallmarks-of-a-sustainable-city.pdf.

CABE (2009) Sustainable Cities, Commission for Architecture and the Built Environment, with Urban Practitioners, http://www.sustainablecities.org.uk.

Calthorpe, P. (1993) The Next American Metropolis: Ecology, Community, and the American Dream. New York: Princeton University Press.

Central Texas Sustainability Indicators Project (2006), http://www.centex-indicators.org.

Ching, J. (2007), Urban Boundary Layer Modeling and Infrastructure Issues, ARL/NOAA – NERL/USEPA, Research Triangle Park, North Carolina.

Echenique, M., Saint, A. (eds) (2001) Cities for the new Millennium, London: Spon Press.

Erell, E. (2008) Effects of Density and Vegetation on the Microclimate of a Modern City in a Desert Environment, Ben Gurion University of the Negev, Israel.

“Florida Green Local Government Standard” (2008) FGBC Green Local Government Standard V2.0, Florida Green Building Coalition, http://floridagreenbuilding.org/files/1/File/GreenLocalGovtv22009Complete12-30-08.pdf

Hardi, P., Zdan, T. (1997) Assessing Sustainable Development, International Institute for Sustainable Development, Canada.

Gehl, J., Gemzoe, L. (1996) Public Spaces, Public Life, Danish Architectural Press, Copenhagen.

Golden, J.S., Jo, J.H., Shin, S.W. (2009) Incorporating Built Environment Factors into Climate Change Mitigation Strategies for Seoul, South Korea: A Sustainable Urban Systems Framework, Habitat International, Volume 33, Issue 3.

Harr, S. (2007) The Ecological City: Metaphor versus Metabolism, Great Cities Institute Publication Number: GCP-07-05, A Great Cities Institute Working Paper, University of Illinois at Chicago.

Hough, M. (1989) City Form and Natural Process: Toward a New Urban Vernacular, London: Routledge.

Ingersoll, R. (2003) A Post-Apocalyptic View of Ecology and Design, Harvard Design Magazine, Spring/Summer 2003, Number 18.

Jenks, M., Kozak, D., and Takkanon, P. (Eds) (2008) World Cities and Urban Form: Fragmented, Polycentric, Sustainable? New York: Routledge.

Jenks, M., Burton, E., Williams, K. (Eds) (1996) The Compact City: a Sustainable Urban Form? London: Spon Press.

Lane, T. (2009) “Tellytubby Land: BedZed Revisited”, Building 2009, http://www.building.co.uk/story.asp?storycode=3143919

Macmillan, S. (2006) Planned Communities and Sustainable Development: A Comparative Review of Recent UK and European Examples.

Martin, L., March, L. (eds.) (1972) Urban Space and Structures, Cambridge University Press, UK.

McPherson, E.G. (1994). “Cooling Urban Heat Islands with Sustainable Landscapes”. In: Rutherford, H.P., R.A. Rowntree and P.C. Muick (eds.). The Ecological City: Preserving and Restoring Urban Biodiversity, Amherst: University of Massachusetts Press:151-171.

Meadows, D. (1998) Indicators and Information Systems for Sustainable Development: A Report to the Balaton Group, The Sustainability Institute, Vermont.

Mills, G. (2005) “Urban Form, Function and Climate”, Dept. of Geography, University of California Davis, epa.gov/heatisland/resources/pdf/GMills4.pdf.

Mills, G. (2004) “The Urban Canopy Layer Heat Island”, IAUC Teaching Resources, www.epa.gov/heatislands/resources/.../HeatIslandTeachingResource.pdf.

Moavenzadeh, F., Hanaki, K., Baccini, P. (2002) Future Cities: Dynamics and Sustainability, Springer.

Oke, T.R. (2009) “The Need to Establish Protocols in Urban Heat Island Work”, Symposium: Urban Scales, Urban Systems and the Urban Heat Island, University of British Columbia, Vancouver.

Pederson, T. (2008) “A Comparative Analysis of Sustainable Community Frameworks”, STAR Community Index, ICLEI – Local Governments for Sustainability.

Planning Policy Statement: Planning and Climate Change (2007) Communities and Local Government, Supplement to Planning Policy Statement 1, Crown Copyright, http://www.communities.gov.uk/publications/planningandbuilding/ppsclimatechange

Platt, R. (2004) “Toward Ecological Cities: Adapting to the 21st Century Metropolis”, Environment, June 2004, Volume 46, Number 5.

Platt, R. H., R. A. Rowntree, and P. C. Muick, eds. 1994. The Ecological City: Preserving and Restoring Urban Biodiversity. Amherst, MA: The University of Massachusetts Press.

Rosenzweig, C., Solecki, W., Pope, G., Chopping, M., Goldberg, R., Polissar, A. (2004) “Urban Heat Island and Climate Change: An Assessment of Interacting and Possible Adaptations in the Camden, New Jersey Region”, New Jersey Department of Environmental Protection.

Ruano, Miguel (2000) Eco-Urbanism – Sustainable Human Settlements: 60 Case Studies, Gustavo Gili.

Schuler, M. (2008) Barrio Avanzado Master Plan Sustainability Guidelines,, Environmental Background and Guidelines for the “New” Toledo, Transsolar, Stuttgart.

Taylor, D. (2008) CABE: Adapting Public Space to Climate Change, Commission for Architecture and the Built Environment, http://www.cabe.org.uk.

Van der Ryn, S., Calthorpe, P. (1986) Sustainable Communities: A New Design Synthesis for Cities, Suburbs and Towns, Sierra Club Books, San Francisco.

Walter, B., Arkin, L., Crenshaw, R. (1992) (ed.) Sustainable Cities: Concepts and Strategies for Eco-City Development, Eco-Home Media.

This document is based on research undertaken while at the University of Cambridge IDBE Program.

Urban Microclimate – Designing the Spaces between Buildings

Evyatar Erell, David Pearlmutter and Terry Williamson

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1. INTRODUCTION: THE PLANNING PROCESS

Modern architecture and urban planning are carried out by professionals from diverse fields. New developments and therefore the design process are driven by market forces in response to demand for housing, retail space, etc. Urban climate considerations must compete for attention and are likely to be addressed by specialist consultants. To be effective, climate consultants must recognize the often competing issues that planners typically face in the preparation of a town plan or an architectural design. In addition, information from multiple and sometimes conflicting sources must be reconciled. The problem is not to produce an idealized plan derived from climatic considerations, but rather to produce a workable plan that is economically viable and accepts that the planner must consider other factors, such as the requirements of transportation systems. Mills (2006) noted that “while the meteorologically ideal settlement serves a useful pedagogical purpose, it does not recognize planning realities where climate issues are rarely a dominant concern”.

2. MICROCLIMATE CONSIDERATIONS IN PLANNING: A PARADIGM

The integration of climate in the planning and design process may be improved if the following principles are observed (Erell, 2008; Mills et al, 2010):

· *Clear definition of goals*: Integration of climate in the planning and design process should not be seen as an end in itself, but rather as a means to achieving certain goals, which may be set by the developer, by planning authorities, or even by the architect himself - but should be clear and well-defined.

· *Unambiguous benefits*: The benefits to be reaped from attaining the goals of the design should be substantial. Their evaluation should take into account complex and realistic scenarios, if necessary using computerized predictive tools (Williamson and Erell, 2008). In the absence of quantitative studies on the effect of proposed designs upon climate, and on the basis of well-documented evidence from other planning professions, decision makers in general tend to downgrade the importance of climatic considerations in urban planning.

· *Integration*: The climatic analysis must be an integral part of the design process. It should be carried out as early as possible, before possible avenues are blocked off by uninformed decisions. Appropriate climatic strategies can rarely be applied retroactively to rectify errors made in the initial stages of the design.

· *Complexity*: In order to analyze a particular question, researchers often study its effects in isolation from other factors that may be involved. However, in real life, narrowly prescribed solutions can yield undesirable outcomes: In order to apply urban climatology effectively in the process of town planning, a comprehensive approach must be adopted, balancing diverse considerations such as pedestrian comfort and building energy savings.

Subsidiarity: While solutions which are applied early in the planning process tend to be the most cost effective, those which may be applied at later stages impose the fewest constraints on the overall design. It is thus of great value to be able to establish the benefits of a particular approach in general terms, without resorting to a unique policy required to achieve the desired goal.

· *Sustainability*: The success of a project is often gauged by its short-term economic return to the developers, so climatologists must be able to collaborate with other members of the design team to assess the economic effects of their recommendations on matters such as street width or building height, which may have significant economic implications. However, any evaluation of long-term sustainability should also take into account social aspects and environmental effects – where the contribution of climatologists may be particularly valuable.

3. CASE STUDIES

The paper will demonstrate the application of these principles in two projects: The first, a small residential complex of single-family detached houses in the desert highlands of Israel, was designed in the 1980s as Israel's first solar neighbourhood. The second, an open-air shopping mall in Beer Sheva that opened in 2010, is an example of how microclimate helped shape a commercial development.

a. Neve Zin neighbourhood, Sde Boqer, Israel[1]

The Neve Zin neighbourhood of Sde Boqer in the Negev desert of Israel comprises a total of 79 private, single-family detached houses. Its significance lies in its unique master plan and building regulations, which were aimed specifically at promoting (though not mandating!) energy-conscious building design and creating an outdoor environment that responds to the local climate. Buildings in the neighbourhood were designed by independent architects commissioned by building owners: The role of the master plan was therefore limited to the creation of a framework within which the architects could operate, rather than to create a design complete in every detail. Design of the neighbourhood began in 1984, and the first buildings were occupied in 1990.

Design goals

Sde Boqer has hot dry summers (on average, temperatures range from 17.3-32.2oC in July) and cool but sunny winters (3.8-14.9oC in January) (Bitan and Rubin, 1994). Average annual rainfall is approximately 80mm. Since solar radiation is plentiful - daily insolation on a horizontal surface averages about 3.3 kWh/m2 in December and 7.7 kWh/m2 in June – so passive solar heating may reduce building energy requirements substantially.

The overall goal of the design was to "create a modern desert neighbourhood that will be responsive to the harsh conditions of the environment and at the same time will provide dwellers with all modern facilities" (Etzion, 1990). This was to be achieved by strategies that deal with a variety of issues, including building thermal performance and pedestrian comfort in outdoor spaces. The design has many innovative aspects, but the following discussion will be limited to the issue of solar rights.

Solar access to all buildings was promoted through several features of the neighbourhood plan, including street orientation, restrictions on building location within each plot and an absolute height limit of 8 meters. In addition, solar access was specifically protected by means of a mandatory solar envelope, which defined the maximum height of any part of a building with respect to its location on the site. The solar envelope was presented in the form of an imaginary plane intersecting the southern-most setback line of a building plot at an angle of 26.5 degrees to the horizon (Figure 1), limiting the height of an adjacent building to the south. The limiting angle was calculated to allow the south façade of each building full exposure to the sun between 8:30 and 14:30 (local time) on the winter solstice, thus guaranteeing solar access throughout winter in the main sunshine hours.

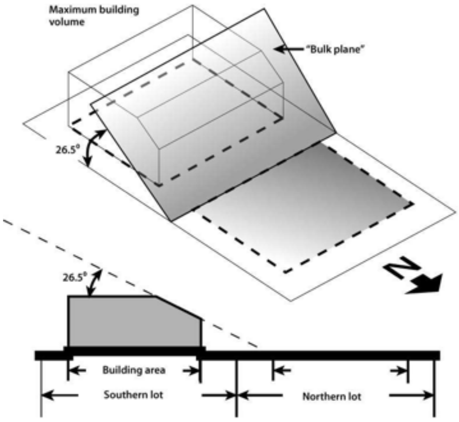

Figure 1: A simple 'solar envelope' guaranteeing solar access to a building, defined by an imaginary inclined plane, above which no part of the adjacent building may project.

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[1] Neve Zin was designed for the Israel Ministry of Housing by the Desert Architecture Unit at the Jacob Blaustein Institute for Desert Research, Ben Gurion University of the Negev. The design team was led by Dr. Yair Etzion.

b. 7th Avenue Mall, Beer Sheva, Israel[2]

In Israel, traditional shopping streets are gradually giving way to malls, of two types: large fully enclosed buildings, air conditioned year round; or suburban ‘power centres’, with low-rise retail buildings surrounding vast parking lots. Beer Sheva’s 7th Avenue Mall, opened in 2010, is an attempt to realize the best of both models. It combines ease of access and convenient parking with modern, pedestrian-friendly open-air shopping.

Design goals

Like most malls, the 7th Avenue Mall combines dining and shopping. The complex aims to provide occupants with comfort and protection from the elements, yet at the same time to be inherently low-energy. The simplest option was to cover and air condition not only the shops, but also the circulation areas, creating one large building. This, however, would not have met the challenge of energy efficiency. Instead the design team sought to modify the microclimate of the main pedestrian axis and outdoor plazas within the development to improve human thermal comfort and to promote activity in these spaces – without resorting to conventional air conditioning of the space.

Climate-related response

The climate of Beer Sheva is similar to that of Sde Boqer, but a little more humid and slightly warmer: mean daily temperatures range from 6.0 to 16.4ºC in January and from 18.5 to 32.9ºC in July. Since winters in Beer Sheva are relatively mild with few rainy days, the climatic design focuses on providing thermal comfort in shopping hours during the hot, dry summer. This was achieved by a comprehensive strategy for reducing radiant loads, promoting air movement and providing evaporative cooling in selected areas.

Shading: The design combines a variety of shading elements to control sunlight in all pedestrian areas. The shading elements include colonnades along the shop fronts on one side of the main north-south axis, pergolas, fixed fabric shading in plazas and moveable fabric awnings extending from one side of the street to the other along the east-west axis (Figure 2). The shading not only reduces the exposure of pedestrians to direct sunlight, but also reduces the amount of light that reaches building surfaces and pavement: these in turn reflect less light and, because they are cooler than exposed surfaces, also emit less radiant heat.

Air movement: Although Beer Sheva experiences a regular westerly breeze in the afternoons and early evening hours, the wind also carries dust and is considered by many to be unpleasant. The main pedestrian axis provides protection from this wind, yet allows some flow of air that may penetrate between the various shading elements constructed at roof height. Air movement is augmented outside shop windows in the covered colonnade by means of mechanical fans, which are operated during the warmest hours of the day (Figure 3).

Figure 2: All circulation areas are shaded by a combination of pergolas and removable fabric awnings.

Figure 3: Ceiling fans promote air movement in shaded areas outside shop display windows.

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[2] The 7th Avenue Mall was designed by Malis Architects for the Shikun U’Binuy Group. The climate consultant for the project was architect Eran Kaftan.

Figure 4: Trees planted along the entire length of the central circulation spine will provide a continuous leaf canopy when mature.

Figure 5: Cafes in the two plazas enjoy evaporative cooling from small fountains and from a downdraft cool tower.

Vegetation: Trees were planted along the entire length of the main axis, primarily to complement the shade canopies and to filter the bright sunlight (Figure 4). When the trees are mature they will provide a continuous leaf canopy. Bushes and flowers planted in shallow planters along the major pedestrian paths enhance the aesthetics but also create a 'softer' visual environment by reducing reflections from the exposed central part of the street.

Evaporative cooling: The Mall has two fairly small open-air plazas, which are surrounded by cafes and restaurants. Each of the plazas has a small water fountain, and is shaded by a tent-like fabric canopy. However, the plazas are dominated by down-draft cool towers 18 meters tall (Figure 5). The towers provide air chilled by evaporation to a temperature of about 22-24 deg C, which is directed to the dining areas adjacent to the pools. Operation of the towers is controlled by computer in response to meteorological data monitored on the roof of the building. Water sprayers are turned on progressively as the air becomes warmer and drier. Air flow is generated by (negative) buoyancy of the relatively cool, moist air, augmented by a mechanical fan capable of delivering 60,000 m3 of air per hour. Wind catchers oriented in the direction of the prevailing wind support pure wind-driven operation when the breeze is sufficiently strong.

4. COMMENTARY

The projects described in the two case studies were designed by architects who were strongly motivated to create environmentally responsive designs. They, in effect, brought their own agenda to projects that could otherwise have evolved differently. Their understanding of the Negev climate led them to establish clear objectives that could be addressed by means of specific architectural responses.

The clients were very different in terms of their policy and degree of involvement in the design process:

Neve Zin was procured by the Israel Ministry of Housing at a time when energy issues were a low priority, and there was no imperative to create a groundbreaking design.

However, to its credit, it was happy to experiment: the project in question was small, located in a rather remote (for Israel) peripheral community and keenly supported by a very involved group of potential residents who were members of the housing association that was to run the community. Unfortunately, although the neighbourhood has proved extremely successful, the Ministry has not adopted its primary features in subsequent projects: climate consultants are usually part of the design team for new developments, but their role is typically minor and climate is not a generator of urban form as it was in Neve Zin.

The 7th Avenue Mall, on the other hand, was designed for a real estate group that has established a policy of supporting environmentally sensitive design and wanted this particular project to be innovative and to stand out from the conventional mall designs. The management was closely involved in the design process and was a partner to all major decisions. The project was carried out within a fairly tight budget and all expenses were monitored closely, but there was full support for the completion of ‘non-essential’ elements such as shading devices and the downdraft cool towers. It is important to note that the effectiveness of these features, and in turn the overall performance of the project, are very much dependent on basic design decisions that were made early in the process.

Each of these two projects is therefore unique in significant ways, and together they show that the successful integration of climatic design principles is often context-specific. While general rules may inform the design process, they do not replace it. It is vital, then, that architects and planners become fluent in the ‘language’ of climatically-informed urban design, and that global imperatives are, in the end, translated into locally appropriate solutions.

REFERENCES

Bitan A. and Rubin S. (1994) Climatic Atlas of Israel for Physical and Environmental Planning and Design. 2nd Ed. Ramot Publishing Company, Tel-Aviv University: Tel-Aviv, Israel.

Erell E. (2008) “The application of urban climate research in the design of cities”. Advances in Building Energy Research, 2:95-121

Erell E., Pearlmutter D. and Williamson T. (2010) Urban climate: Designing Spaces Between Buildings. Earthscan/James & James Science Publishers, London, 266p.

Etzion, Y. (1990) “A desert solar neighborhood in Sde Boqer, Israel”. Architectural Science Review, 33:105-111.

Mills G. (2006) “Progress toward sustainable settlements: a role for urban climatology,” Theoretical and Applied Climatology 84, 69-76.

Mills G., Cleugh H., Emmanuel R., Endlicher W., Erell E., McGranahan G., Ng E., Nickson A., Rosenthal J. and Steemer K. (2010) "Climate Information for Improved Planning and Management of Mega Cities (needs perspective)". Procedia Environmental Sciences, 1:228-246.

Williamson T. and Erell E. (2008). “The Implications for Building Ventilation of the Spatial and Temporal Variability of Air Temperature in the Urban Canopy Layer”. International Journal of Ventilation, 7(1):23-35.

Cool Neighborhoods within the New York Metro Heat Island

Jennifer R Cox

1. Introduction

One of the many multi-faceted environmental problems of the 21st century is the 'growth induced' urban heat island (UHI) effect, wherein the surface air temperatures above urban areas of a given metropolitan area are observed to be higher than those of surrounding rural areas. Figure 1 depicts present-day land surface temperature (LST) and surface heat island (SHI) variations within the New York Metro Heat Island as they are captured by the MODIS 8-Day LST bands. These LST and SHI variations may seem trivial, UHI effect is known to lead to increased energy use (Sailor and Lu, 2004), air pollution (Taha et al., 1997) and have implications on precipitation patterns (Lowry, 1992) and public health. Significantly, during extreme heat weather conditions the UHI effect contributes to increased mortality rates as observed in Chicago (Klinenberg, 2002), Paris (Dhainaut et al. 2004), and New York City (New York City Department of Health and Mental Hygiene, 2006). It is not surprising that mitigating and managing the UHI effect has become a major objective for the fields of planning and urban climatology in order to reduce its contribution to other environmental problems.

The UHI effect is created when naturally vegetated surfaces are replaced with impervious surfaces such as concrete, asphalt, and bricks. These impervious surfaces trap heat, warming the climate within a given location because the benefits of natural vegetation are no longer present. Those benefits include: shade for buildings, the interception of solar radiation, and the cooling of the surrounding air by evapotranspiration. Consequently the process of urbanization radically changes the surface and atmospheric properties of a given area, in a way that directly and indirectly modifies the area's energy and water balance. Specifically, the direct impact occurs during the transformation of stored chemical energy into anthropogenic heat, which produces excess heat eventually, dissipated into the atmosphere as sensible heat (Landsberg, 1981; Oke, 1988).

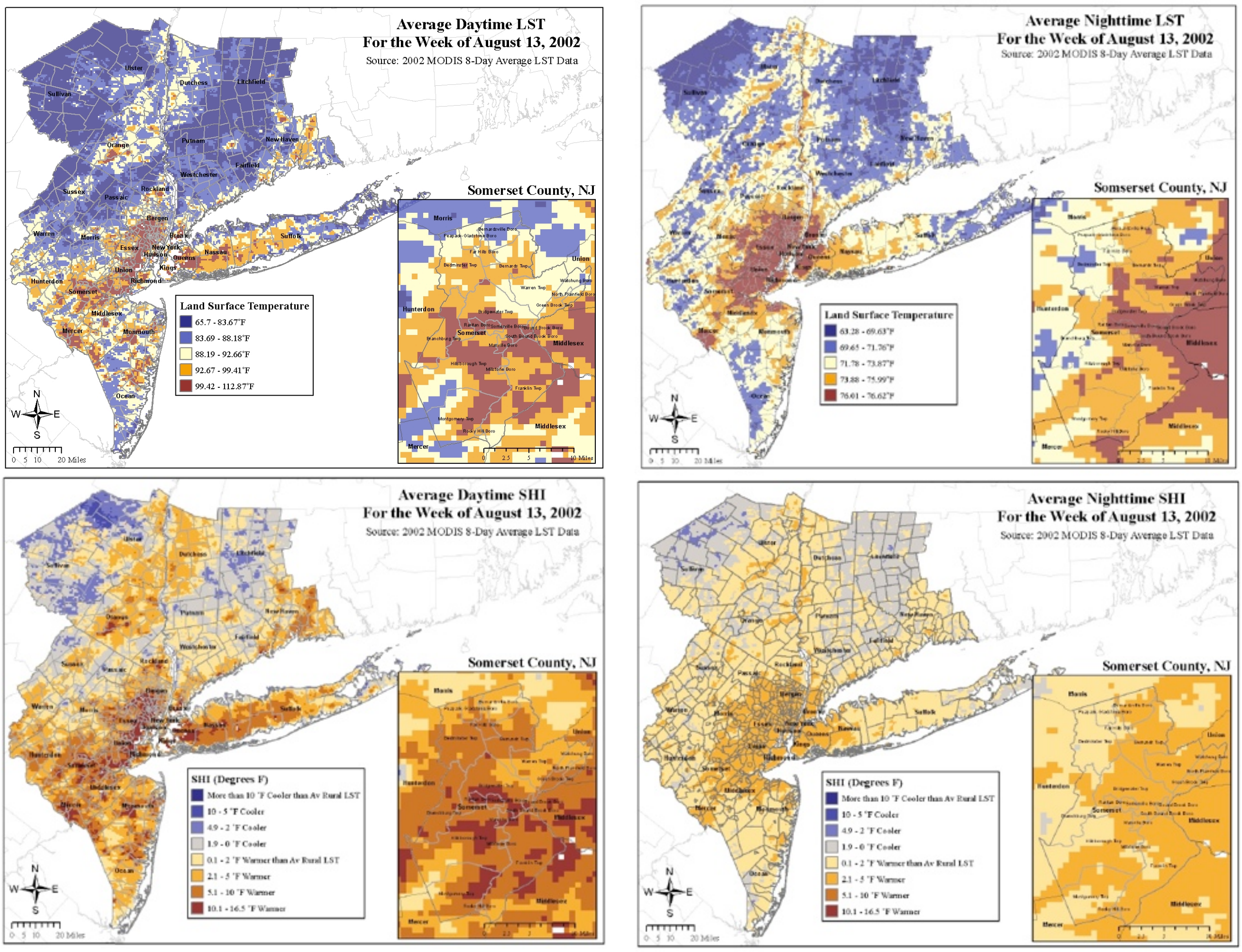
For more than one hundred and fifty years, suburban expansion located along the urban-rural fringe has been the dominant form of urban development in the New York–New Jersey-Connecticut Metropolitan region (Metro region). This expansion is measured using a distance indicator that marks the location of the Metro region's urban-rural fringe. Hayden (2003) documents 'Boardlands' development during the 1820s was less than one mile from Downtown New York. The current urban-rural fringe is located more than seventy-five miles away from the City of New York. The currently suburban spatial development densities, which include: exurban, suburban and inner ring suburban densities, cumulatively represent more than 65% of the Metro region. Meanwhile, the compact urban densities represent less than 5% of the Metro region.

Suburban living was inspired by the utopian and progressive movements of the late 19th century, led by urban planners who sought to improve industrial workers' dense urban living conditions through the regulation of local buildings and land uses (Hall, 2002; Levy, 2003). These movements supplied a variety of innovative ideas and concepts that would guide future development pattern in this region.

The city beautiful movement, which called for the creation of new laws to regulate future development (buildings and land uses) would lead have a lasting impact on the development patterns observed today. The movement, brought on by a series of locally driven development interventions in the early 1880s was reactive instead of proactive in leading future development. The first intervention focused on the loss of light and air quality due to the compact nature of tall residential buildings in Lower Manhattan. In response, the New York State legislature enacted the Tenement House Act of 1901 that included a series of height restrictions on new residential buildings. In 1915, the second intervention was brought on by the completion of the Equitable Building, the first modern skyscraper designed by Ernest Graham. The invention led to the adoption of the 1916 Zoning Resolution, which gave local governments the ability to control land use and density. Drafted by Edward Bassett, the Standard Enabling Act was adopted by most states, enabling their municipalities the ability to enact similar zoning laws (Levy, 2003).

In the Metro region there are over five hundred local governments, each implementing their own local land use policies; and the result is a 'de facto' regional land use policy made up of local land use policies that enable the dominant form of suburban spatial development through municipal zoning regulations. These policies generally neglect the cumulative effect the local land use policies. Stone (2004) confirms these local land use policies lead to increasingly impervious environments with more buildings, parking lots, roads, driveways, and sidewalks and less undeveloped areas including natural grasslands, wetlands, and trees. An increasingly impervious environment then leads to increasingly multifaceted '21st century' environmental problems.

Even though suburban development overwhelms today's regional landscapes, the majority of the research on the UHI effect has focused on urban areas where UHI intensity is greatest. As example, in the Metro region, most research has focused on assessing and mitigating the UHI effect for the City of New York



Average Daytime LST
For the Week of August 13, 2002
Source: 2002 MODIS 8-Day Average LST Data

Average Nighttime LST
For the Week of August 13, 2002
Source: 2002 MODIS 8-Day Average LST Data

Average Daytime SHI
For the Week of August 13, 2002
Source: 2002 MODIS 8-Day Average LST Data

Average Nighttime SHI
For the Week of August 13, 2002
Source: 2002 MODIS 8-Day Average LST Data

Figure 1: Weekly Remote Sensing Imagery Captures the Regional Land Surface Heat Island for New York Metro Heat Island

(Gedzelman, 2003; Rosenzweig and Solecki, 2006; Gaffin et al, 2007) and other large cities such as Camden and Newark, NJ (Solecki, et al 2003). Only a small subset of UHI studies are focused on suburban microclimates (Landsberg, 1981; Oke; 1984; Bonan, 2000; Hinkel et al., 2003; Soleki et al., 2003; Hartz et al., 2006). Even less research is focused on the role of suburban expansion on the formation of UHI (Stone and Norman, 2006) or the significance of the impact that land use policy has on UHI effect (Wilson et al., 2003). The goals is to better understand the local land use policies that create cool neighborhoods and to learn how weather and climate science were applied or ignored in the design and management of these areas. To accomplish this objective, this research highlights an analysis of suburban residential zoning regulations' minimum tax lot size requirements and their influence on vegetation and brightness temperature.

2. Background

For over 2,000 years, scientists have observed urban climate as it relates to urban planning and regional design (Golany, 1996). Documentation of these relationships has been formally studied for less than eighty years (Oke, 2006). Research specific to the Metro region is documented for less than fifty years.

The regional research has focused on analysis of both the atmospheric- and the satellite- based measurement of the UHI effect.

There is a slightly longer history of New York (NY) based researchers examining UHI as it pertains to urban air dynamics. Those researchers include: Scudder (1965), who focused on wind dynamics over New York; and Davidson (1967), who summarized urban air pollution dynamics; and Bornstein (1968), who focused on horizontal and vertical temperature distribution over the metropolitan region. More recently, meso-scale numerical modeling of UHI that offers robust explanations of synoptic weather conditions impacts has been conducted by Rosenzweig and Solecki (2001), Gedzelman, et al. (2003), Childs and Raman (2005), Rosenzweig and Solecki (2006) and Gaffin et al. (2007).

In the late seventies, surface heat island (SHI) research methods were first employed by Price (1979) to describe the relative warming and excess energy by municipality, highlighting greater excess in suburban densities. Rosenzweig and Solecki (2006) utilized moderate-resolution land surface temperature data to analyze New York City's UHI relationship to land use, concluding that NYC's UHI consists of an archipelago of hot and cool areas.

Rosenzweig et al (2009) provide benefits of an interdisciplinary approach to analyzing more robust and comprehensive assessment of both the atmospheric- and surface heat island effect to mitigation the effect for the City of New York.

To critically describe the interplay between the SHI and the role that land use policy plays in the generation and expansion of the effect, the suburban county of Somerset County, New Jersey is chosen as a study area. Located 58 miles west-southwest of the City of New York, the county is made up of twenty-one local governments of which there are twelve boroughs and nine townships. Each municipality maintains separate elected officials, town planning and zoning boards that guide the development that takes place within the jurisdiction's bounds. As tax lot owners, county, regional, and state government agencies also dictate land use policy on their properties. As a result, land development policies may not be aligned across the different agencies; and therefore conflicting policies may be implemented.

3. Data and Methods

3.1 Satellite Imagery

Landsat 7 Enhanced Thematic Mapper Plus (ETM+) is employed in this research. There are eight sensors onboard Landsat 7. Bands 1 through 7 have a spatial resolution of 30 meters, with the exception of Band 6 (Thermal), with a spatial resolution of 60 meters. Band 8 (panchromatic) has a spatial resolution of 15 meters. All the bands can collect one of two gain settings (high or low) for increased radiometric sensitivity and dynamic range, while Band 6 collects both high and low gain for all scenes (USGS, 2011).

Landsat 7 ETM+ data is indexed using the Worldwide Reference System-2 (WRS-2) path/row system. The approximate scene size is 170 km north-south by 183 km east-west (106 mi by 114 mi) (USGS, 2011). Four scenes are needed to cover the entire Metro region. However for this application, only one scene (path/row 14/32) is practical; it covers the City of New York and a large portion of central and northern New Jersey. Employed in Rosenzweig and Solecki (2006), the scene captured on August 14, 2002 at 10:30am is relatively cloud-free. The Brightness Temperature is generated for the August 2002 thermal bands and a commonly used normalized difference vegetation index (NDVI) is generated to detect the presence of vegetation.

The Brightness Temperature data employed in this research was generated by Rosenzweig and Solecki (2006); and is based on the methods of Nichols et al. (1996) and Chander and Markhem (2003). The data is converted from Kelvin to Fahrenheit, which in the U.S. standard in weather reporting and therefore assumed to resonate more easily with decision makers and the general public that may utilize the results and recommendations of this research.

The Normalized Difference Vegetation Index (NDVI) data employed in this research was generated in Rosenzweig and Solecki (2006). NDVI is a straightforward numerical indicator used to analyze remote sensing measurements to assess whether the target being observed contains live green vegetation. NDVI is calculated from the Near-Infrared (Band 4) and Red (Band 3) bands as follows:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

Where NIR is the Near-Infrared band or Band 4 of the Landsat ETM+ data and RED is the Red bandwidth or Band 3 of the Landsat ETM+ data.

NDVI generally varies between -1.0 and +1.0. Very low values or negative values of NDVI (0.1 and below) typically correspond to barren areas of rock or sand. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate forests and tropical rainforests (0.6 to 0.8). The NDVI values in Somerset County New Jersey range from -0.45 to 0.42, which are consistent with what is expected for the present amount of suburban spatial development and lack of vegetation surfaces in this metropolitan region.

Geospatial data

3.2.1 Tax lots

The tax lot data is the study unit of analysis because it is considered the mechanism by which the land use policy is implemented (Stone and Norman, 2006). The zoning districts, regulations, NDVI and brightness temperature metrics are all joined to the tax lot data for the qualitative and quantitative analysis.

3.2.2 Zoning Maps and Regulations

The zoning maps and regulations are the critical link to describing the influence of the local development on the underlying land surface conditions and thermal impacts. The state geospatial data repository, which is called the New Jersey Geospatial Information Network (NJGIN, 2011) provides web access of the twenty-one municipalities in Somerset County, New Jersey. The zoning district maps and regulations are not consistent from municipality to municipality. In fact, their development, organization, and level of detail are based on the discretion of each implementing local government. At the very least, these regulations typically maintain minimum standard requirements for the development of tax lots falling within a given zoning district. The county geography is explored to describe potential cumulative effect of local land use policy.

The zoning district maps do not contain information pertaining to the development regulations of the zoning district. Unfortunately, only the zoning districts maps are available on the web mapping application. The regulations are maintained in each municipality’s code of regulations. In addition to zoning regulations, there are many regulations in the code of regulations, noise regulations are examples of a type of additional localized regulations. Only the zoning regulations are maintained by the Municipality’s Zoning and/or Planning Boards. Anecdotally, during this data collection it is noticed that an increasing number of municipalities are scanning their zoning regulations and maintaining them electronically for future use. At the time of this research, approximately half of the twenty-one municipalities studied maintained electronic versions of the zoning regulations.

3.3 Methods

In this research, the methodological approach is based on a combination of methods previously applied by Stone and Norman (2006) and Wilson et al. (2003) to optimize the ability to analyze local land use policy and its influence on suburban component of the heat island effect. The approach considers the limitations of Landsat thermal data; while taking advantage of the high resolution local tax lot and zoning data that is available.

It is known that vegetation plays a key role in the regulation of land surface temperature, and an even stronger role in reducing the UHI effect than low-albedo (highly reflective) surfaces (EPA, 2011; Goward, 1985). Stone's (2004) "Paving Over Paradise" research documents that suburban spatial development and the overall suburban landscape are increasingly characterized as having more man-made surfaces (i.e. concrete, asphalt, bricks, lumber) and less vegetated surfaces (i.e. trees, grasses, and wetlands). Vegetation indexes are commonly generated to determine the presence of vegetation provides a comparative baseline of the effect.

Techniques are crafted to analyze the land use policy's influence on the underlying land surface conditions, mainly the presence of vegetation though the NDVI values and SHI through Brightness Temperature values. Land use policy is analyzed vis-à-vis tax lot zoning regulations, specifically the minimum lot size requirements. Lot sizes are grouped together with like sizes.

4. Analysis

Analysis objective is to Analysis results are presented in two parts as follows: 1) the suburban land use policy assessment and 2) the quantitative results.

4.1 Suburban Land Use Policy Assessment

4.1.1 Residential vs. Non-Residential Areas

The zoning data is reviewed to generate a parcel-based map that depicts residential and non-residential areas. To categorize the parcel data into these two categories, each municipality's zoning map is reviewed using the Somerset County ARCGIS web-mapping application available through NJGIN. The process is validated using aerial photography.

All 127, 274 tax lots in Somerset County are analyzed. Approximately, 91% of the total number of all parcels in the study area maintains residential land uses and the remaining 9% maintain non-residential land uses. In terms of land area, approximately 75% of the county's total area in acres is considered residential land. Figure 2a illustrates the county land use is predominantly residential.

4.1.2 Residential Zoning Districts

Of the 369 zoning districts, only the 193 residential land use districts are assessed. This assessment indicates that the grouping the residential zoning districts by their naming conventions does not provide an effective means to quantify the influence of tax lot size on NDVI and Brightness Temperature. This is because the assessment reveals that similarly named residential zoning districts do not necessarily provide a consistent mechanism to grouping tax

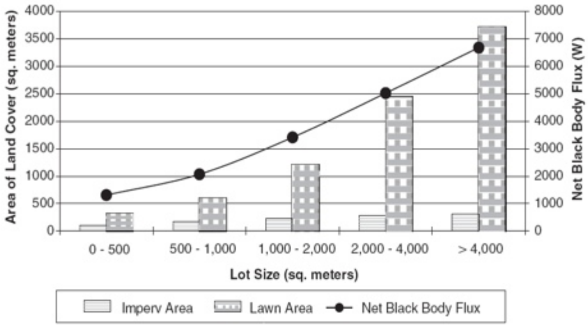
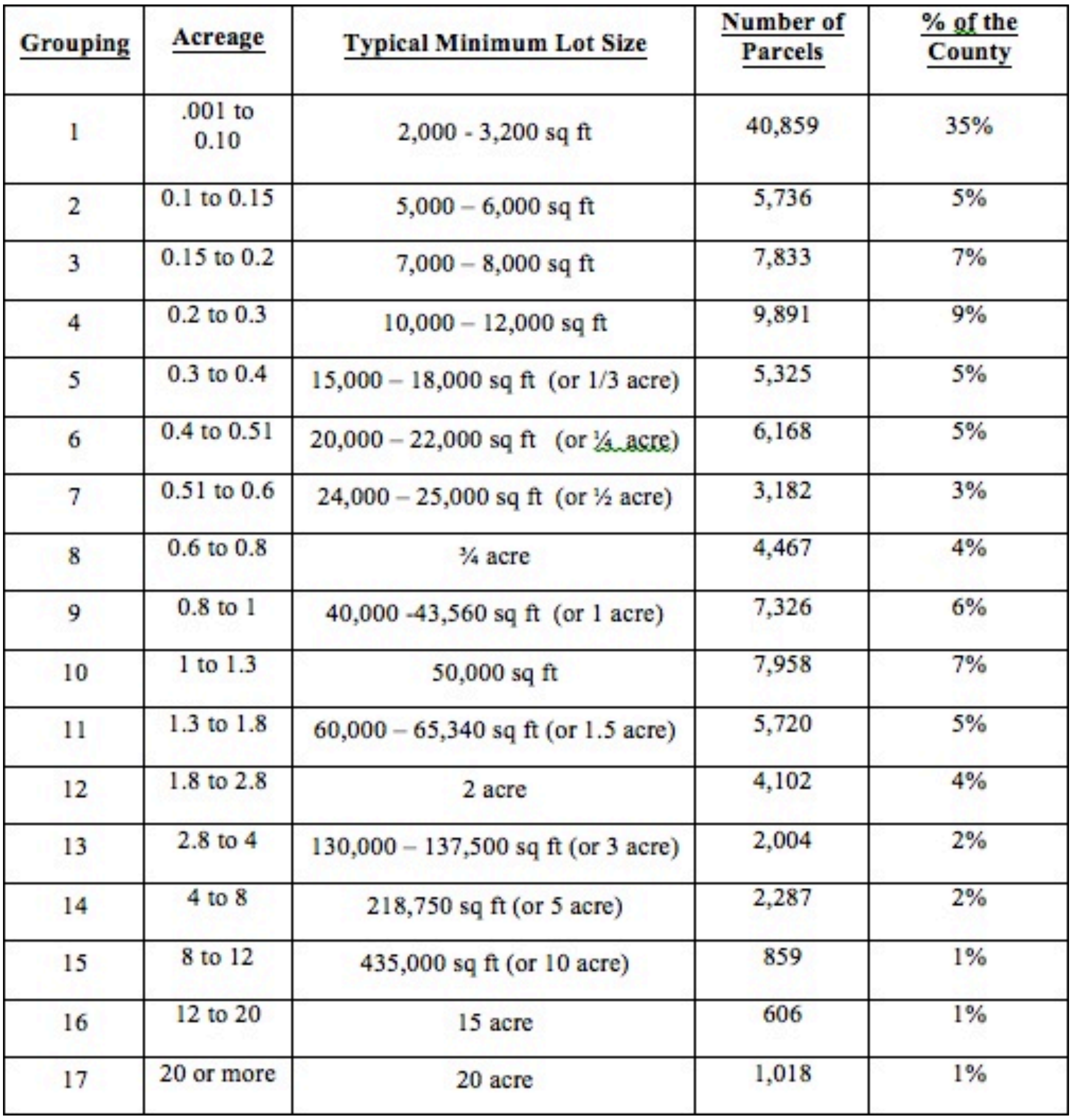


Figure 3: Mean Land Cover Area and Net Black Body Flux by Lot Size

Sources: Stone and Norman (2006)

Table 1: Typical Minimum Lot Size in the Municipal Zoning Regulations



Grouping	Acreage	Typical Minimum Lot Size	Number of Parcels	% of the County
1	.001 to 0.10	2,000 - 3,200 sq ft	40,859	35%
2	0.1 to 0.15	5,000 – 6,000 sq ft	5,736	5%
3	0.15 to 0.2	7,000 – 8,000 sq ft	7,833	7%
4	0.2 to 0.3	10,000 – 12,000 sq ft	9,891	9%
5	0.3 to 0.4	15,000 – 18,000 sq ft (or 1/3 acre)	5,325	5%
6	0.4 to 0.51	20,000 – 22,000 sq ft (or ¼ acre)	6,168	5%
7	0.51 to 0.6	24,000 – 25,000 sq ft (or ½ acre)	3,182	3%
8	0.6 to 0.8	¾ acre	4,467	4%
9	0.8 to 1	40,000 -43,560 sq ft (or 1 acre)	7,326	6%
10	1 to 1.3	50,000 sq ft	7,958	7%
11	1.3 to 1.8	60,000 – 65,340 sq ft (or 1.5 acre)	5,720	5%
12	1.8 to 2.8	2 acre	4,102	4%
13	2.8 to 4	130,000 – 137,500 sq ft (or 3 acre)	2,004	2%
14	4 to 8	218,750 sq ft (or 5 acre)	2,287	2%
15	8 to 12	435,000 sq ft (or 10 acre)	859	1%
16	12 to 20	15 acre	606	1%
17	20 or more	20 acre	1,018	1%

lots by their overall size. In terms of similar minimum lot size requirements, assessment indicates there is lack of regional consistency between what municipalities consider as low-, medium-, high- density, and/or rural residential.

The tax lot size requirements of the zoning regulations are important to this research because Stone and Norman (2006) research indicates that low density residential spatial development has a greater thermal footprint (black body flux) than higher density residential development. In addition, Stone and Norman (2006) found that impervious surface coverage per tax parcel is not the primary driver of the expansion of the UHI effect; instead, they found that the lawn area of a parcel has 'the strongest association with the net black body flux.'

4.1.3 Minimum Lot Size Requirements

Assessing the minimum lot size requirements for all the residential municipal zoning regulations provides an opportunity to conduct a comparative regional local land use policy assessment. Typical minimum lot size is recorded in a municipality's zoning regulations as both square feet and acres. It is determined that the combination of metrics is not uncommon from municipality to municipality. The reason why both metrics were employed to define the districts is unapparent. Perhaps the combination of metrics is a result of previous British town planning and American planning disciplines' influence on today's municipal zoning regulation.

Table 1 depicts the typical minimum lot sizes within municipality's zoning regulations, total number of parcels in the groupings, and

Figure 2a

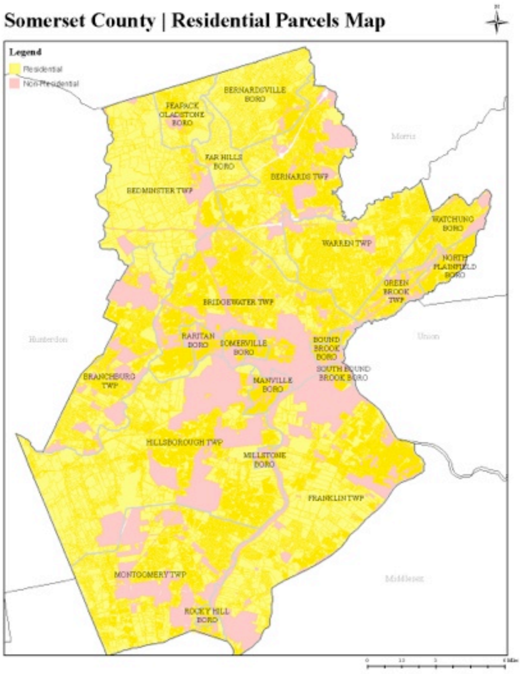


Figure 2b

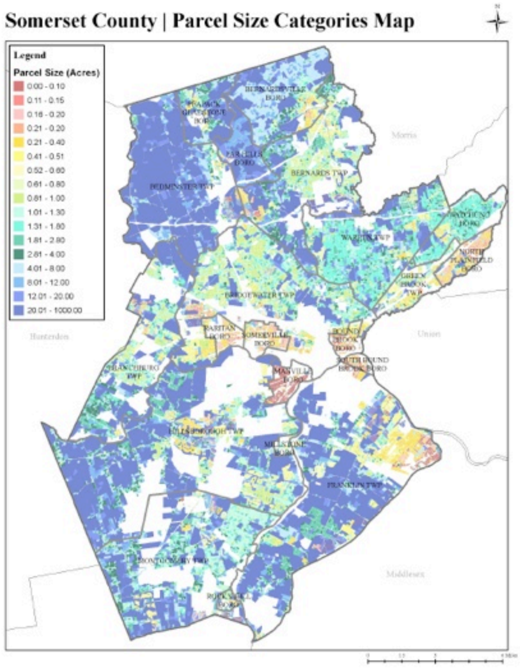


Figure 2c

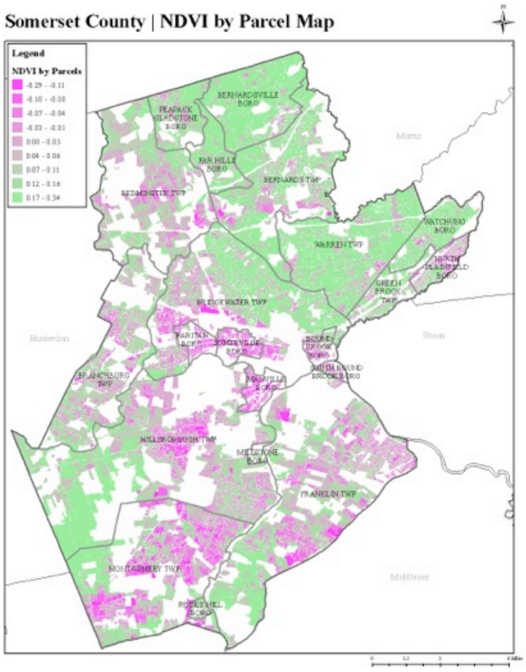
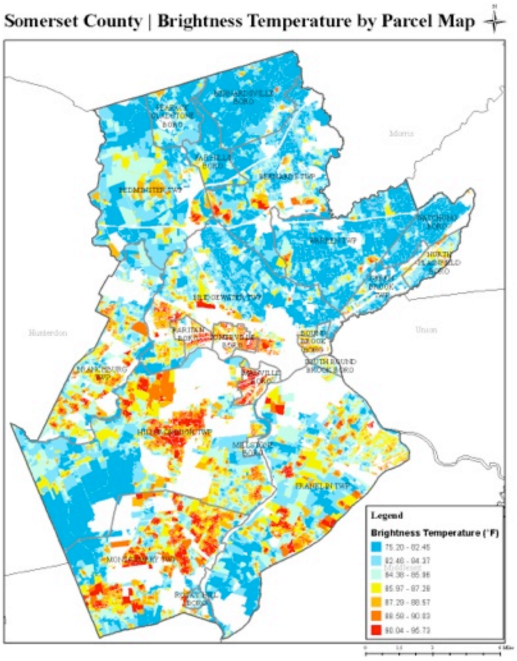


Figure 2d



percentage of total residential parcels county. Figure 2b provides a map illustration of the minimum lot sizes.

Last step of this analysis includes grouping the residential tax lots into similar minimum lot size categories to allow for quantitative analysis of the minimum lot size requirements and their influence on NDVI and Brightness Temperature.

4.1.4 NDVI and Brightness Temperature Metrics by Tax Lot

A simple zonal function in the GIS is employed to produce parametric measures of NDVI and Brightness Temperature for each residential tax lot. Maps of the average NDVI and Brightness Temperature by tax lot are depicted in Figure 2c and 2d.

4.2 Quantitative Analyses by Minimum Lot Size Groupings

4.2.1 Descriptive Statistics of NDVI and Brightness Temperature

For all seventeen minimum lot size groupings, the mean and standard deviation NDVI and Brightness Temperature metrics are assessed. Figure 4a and 4b present two charts that summarize the mean and standard deviation differences for the NDVI metrics and Brightness Temperature by minimum lot size grouping.

4.2.2 Analysis if the Variance of Mean Values

The one-way analysis of variance (ANOVA) test evaluates the significance of differences in the mean NDVI and Brightness Temperature values associated with lot size groupings. Results of the

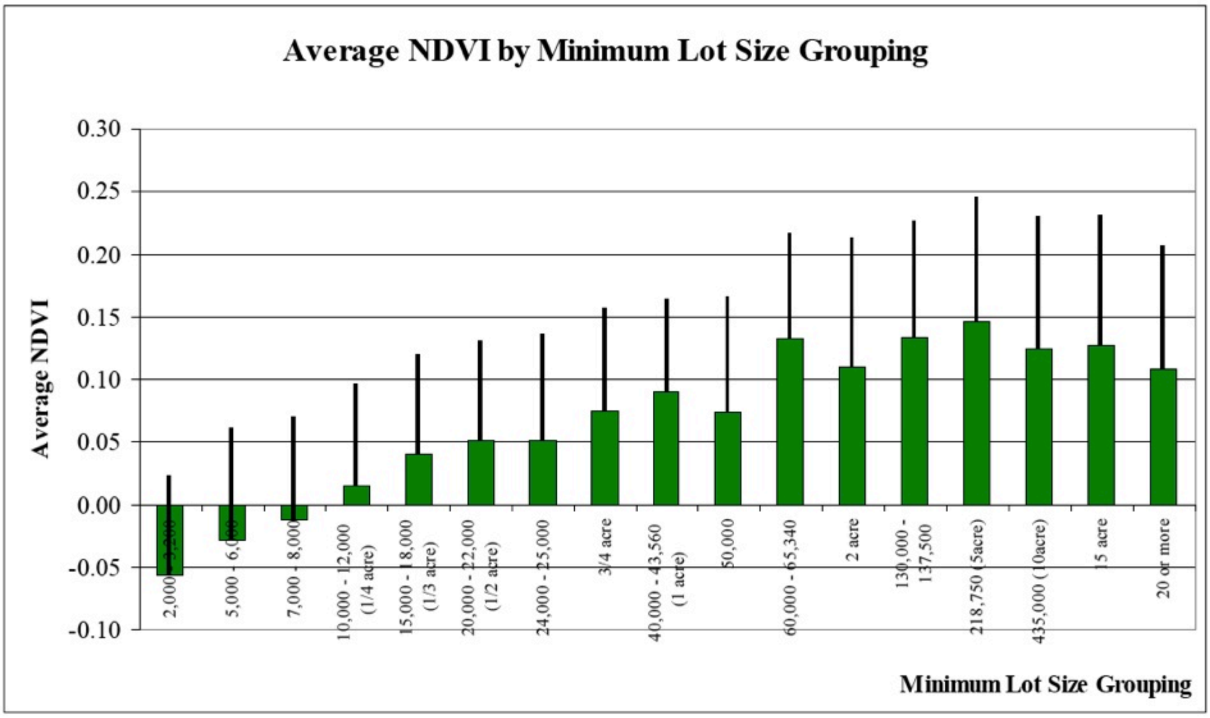


Figure 4a

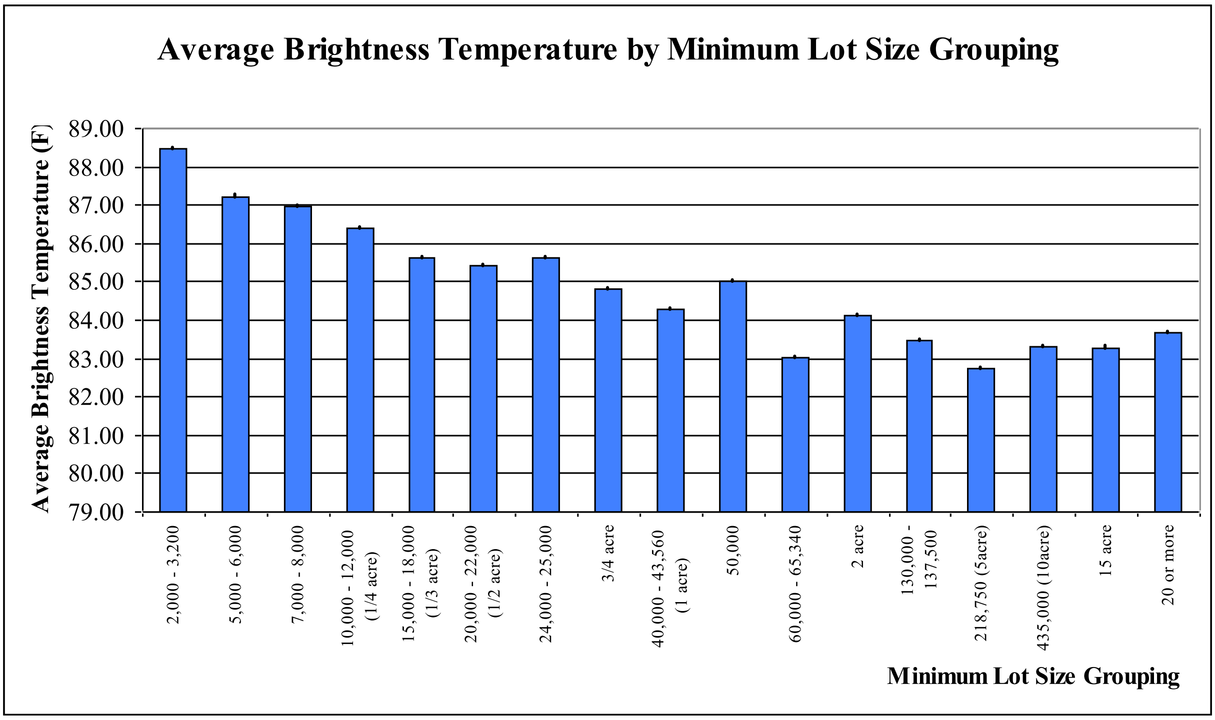


Figure 4b

ANOVA tests indicate that the mean NDVI and Brightness Temperature averages by lot size grouping are significantly different by lot size. Results imply that on average the sizes of tax lots have significantly different impacts on mean NDVI and Brightness Temperature values as measured by the Landsat ETM+ satellite sensor.

While, the results of the ANOVA test indicate there are some significant differences between the mean NDVI and Brightness Temperature values groupings. However, these results do not provide information on which lot size groupings differ. A post-hoc test called Tamhane's T2 is employed to determine how each lot size groupings differs from the others. N this research, it is referred to as a comparison of means.

4.2.3 Comparison of Means

Each of the groupings is compared to the other groupings through use of Tamhane's T2 statistic, which is similar to a student t-test, but decreases the chance of committing a Type I error when determining whether to accept or reject the null hypotheses. As compared to other post-hoc tests, this statistic is appropriate for this analysis because categories maintain unequal sample sizes (Hochberg and Tamhane, 1987).

Tables 2a and 2b depict the results of the employed Tamhane post-hoc test. The values in bold black type indicate cases where the mean critical values exceeded 95% confidence levels. Of the 136 possible lot size groupings, 122 groupings exhibited significantly different mean Brightness Temperature values. Of the 136 possible lot size groupings, 124 groupings exhibited significantly different mean NDVI values.

The one-way ANOVA analysis provides evidence that the lot sizes, which is dictated by the minimum lot size requirements in the zoning regulations, influences the Brightness Temperature and NDVI value differently. The quantitative results indicate there is a strong influence on land surface temperature and the presence of vegetation when grouped by minimum lot size based on zoning regulations.

4.2.4 Relationship between NDVI and Brightness Temperature

Once it is determined that minimum lot size is influencing the NDVI and Brightness Temperature differently, the next step is to describe the degree of linear relationship between two variables the Pearson's correlation coefficient is employed. The results of the correlation coefficients range in value from -1 (a perfect negative relationship) and +1 (a perfect positive relationship). A value of 0 indicates no linear relationship. This statistic assumes the variables are normally distributed. The prior analysis suggests the data is normally distributed.

For each of the lot size groupings, Pearson's Correlation Coefficient is examined to assess the relationship between NDVI and Brightness Temperature. Generally, the NDVI is negatively

Table 2a

Tamhane's T2 Multiple Comparison Table of Mean Differences in Brightness Temperature for the Lot Size Groupings

Category	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1		**1.24**	**1.50**	**2.09**	**2.85**	**3.04**	**2.84**	**3.68**	**4.18**	**3.47**	**5.46**	**4.35**	**5.02**	**5.73**	**4.17**	**5.19**	**3.56**
2			**0.26**	**0.85**	**1.61**	**1.80**	**1.59**	**2.43**	**2.93**	**2.23**	**4.22**	**3.11**	**3.77**	**4.49**	**3.93**	**3.95**	**3.56**
3				**0.59**	**1.35**	**1.54**	**1.33**	**2.17**	**2.67**	**1.97**	**3.96**	**2.85**	**3.51**	**4.23**	**3.67**	**3.39**	**3.30**
4					**0.76**	**0.96**	**0.75**	**1.59**	**2.09**	**1.38**	**3.37**	**2.27**	**2.93**	**3.64**	**3.08**	**3.10**	**2.71**
5						**0.19**	-0.02	**0.82**	**1.33**	**0.62**	**2.61**	**1.50**	**2.16**	**2.88**	**2.32**	**2.34**	**1.95**
6							-0.21	**0.63**	**1.13**	**0.43**	**2.41**	**1.31**	**1.97**	**2.69**	**2.12**	**2.15**	**1.76**
7								**0.84**	**1.34**	**0.63**	**2.62**	**1.52**	**2.18**	**2.90**	**2.33**	**2.36**	**1.96**
8									**0.50**	-0.21	**1.78**	**0.68**	**1.34**	**2.06**	**1.49**	**1.52**	**1.12**
9										**-0.71**	**1.28**	0.18	**0.84**	**1.55**	**0.99**	**1.01**	**0.62**
10											**1.99**	**0.88**	**1.55**	**2.26**	**1.70**	**1.72**	**1.33**
11												**-1.10**	**-0.44**	0.27	-0.29	-0.27	**-0.66**
12													**0.66**	**1.38**	**0.81**	**0.84**	**0.45**
13														**0.71**	0.15	0.17	0.22
14															**-0.56**	-0.54	**-0.93**
15																0.02	-0.37
16																	0.39

Values in BOLD Black type indicate pairs that maintain critical values that exceeded 95% confidence levels.

Table 2b

Tamhane's T2 Multiple Comparison Table of Mean Differences in NDVI for the Lot Size Groupings

Category	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1		**-0.03**	**-0.05**	**-0.07**	**-0.10**	**-0.11**	**-0.11**	**-0.13**	**-0.15**	**-0.13**	**-0.19**	**-0.17**	**-0.19**	**-0.20**	**-0.18**	**-0.18**	**-0.17**
2			**0.03**	**-0.02**	**-0.04**	**-0.68**	**-0.08**	**-0.10**	**-0.12**	**-0.10**	**-0.16**	**-0.14**	**-0.16**	**-0.17**	**-0.15**	**-0.15**	**-0.14**
3				**-0.26**	**-0.05**	**-0.06**	**-0.06**	**-0.09**	**-0.10**	**-0.09**	**-0.14**	**-0.12**	**-0.15**	**-0.16**	**-0.14**	**-0.14**	**-0.12**
4					**-0.03**	**-0.04**	**-0.04**	**-0.06**	**-0.08**	**-0.06**	**-0.12**	**-0.09**	**-0.12**	**-0.13**	**-0.11**	**-0.11**	**-0.09**
5						**-0.01**	**-0.01**	**-0.04**	**-0.05**	**-0.03**	**-0.09**	**-0.07**	**-0.09**	**-0.11**	**-0.08**	**-0.09**	**-0.07**
6							0.00	**-0.02**	**-0.04**	**-0.02**	**-0.82**	**-0.06**	**-0.08**	**-0.09**	**-0.07**	**-0.08**	**-0.06**
7								**-0.02**	**-0.04**	**-0.02**	**-0.08**	**-0.06**	**-0.08**	**-0.09**	**-0.07**	**-0.75**	**-0.06**
8									**-0.01**	0.00	**-0.57**	**-0.03**	**-0.06**	**-0.07**	**-0.05**	**-0.05**	**-0.03**
9										**0.02**	**-0.04**	**-0.19**	**-0.04**	**-0.06**	**-0.03**	**-0.04**	**-0.02**
10											**-0.06**	**-0.04**	**-0.06**	**-0.07**	**-0.05**	**-0.05**	**-0.03**
11												**0.02**	0.00	**-0.01**	0.01	0.01	**0.02**
12													**-0.02**	**-0.04**	**-0.01**	-0.02	0.00
13														**-0.01**	0.01	0.01	**0.02**
14															**0.02**	**0.02**	**0.04**
15																0.00	0.15
16																	-0.18

Values in BOLD Black type indicate pairs that maintain critical values that exceeded 95% confidence levels.

correlated with Brightness Temperature. The results indicate that the overall study area presents the strongest correlation between Brightness Temperature and NDVI (-0.847). By lot size groupings, the strongest correlation between Brightness Temperature and NDVI is found over the 12 acre lot size group (-0.901), followed by 435,000 sq. ft. (8-12 acre) lot size group (-0.894). The least correlation is found over the smallest lot sizes or the 2,000-3,200 sq. ft. lots. All correlations were statistically significant to 95% percentile. Table 3 shows the correlations by lot size groupings.

Figure 5 depicts scatterplots of Brightness Temperature and NDVI are analyzed for each lot size grouping to visually determine the linear relationship. As expected, the linear relationship grows stronger as the lot sizes increase. This means the larger lot sizes maintain greater amounts of vegetation.

Once the degree of the relationship between the Brightness Temperature and presence of vegetation (NDVI) is established, an ordinary least squares regression (OLSR) is employed to explore the strength of the linear relationship.

4.2.5 Strength of NDVI as an Explanatory Variable for Brightness Temperature

A simple bi-variate OLSR is used to predict the values of one variable, given the values of another variable. In this research, predicting Brightness Temperature from the NDVI variable is desired. Each variable's values are plotted on a graph, with Brightness Temperature as the dependent variable and NDVI as the independent variable. If there is a perfect linear relationship between Brightness Temperature and NDVI, then all the sample points on the graph would fit on a straight diagonal line. A perfect relationship is the value of +/- 1 and no relationship is 0.

Table 3 presents the results of the regression coefficients of determination (R2) between Brightness Temperatures with NDVI for each of the lot size groupings. All correlations are statistically significant to the 95% percentile. These values are greater than they are for similar analyses performed in Rosenzweig and Solecki (2006), which suggests that in suburban landscape presence of vegetation is a much stronger explanatory variable than it is in dense urban setting.

The results can be grouped into three categories based on the amount of variation in Brightness Temperature that can be explained by the independent variable NDVI. The minimum lot size groupings where approximately more than three-quarters of the Brightness Temperature can be explained by the NDVI values, which is significant as these groupings are all regulated by zoning that calls for minimum lots sizes greater than one acre. In these groupings, the zoning regulations determined typically maintained

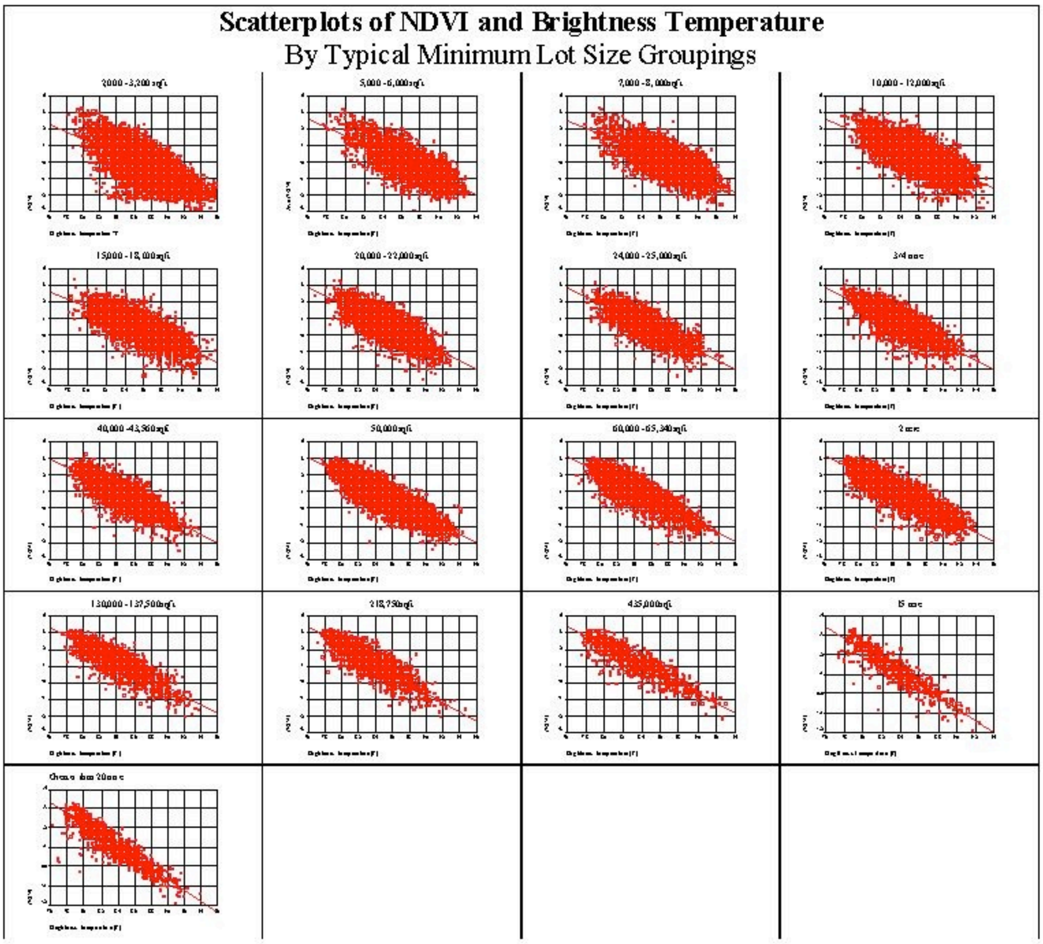


Figure 5

maximum impervious coverage requirements, and those requirements are between 5-20% impervious per tax lot. The result is 80% to 95% of the tax lots in these groupings are generally more previous or naturally vegetated than the other groupings.

The minimum lot size groupings with approximately two-thirds of the Brightness Temperature can be explained by the NDVI is also a significant finding because the municipal zoning regulations for these groupings maintain a much wider range of maximum impervious coverage requirements. The requirements are between 10% and 65%. The majority appear to be at 30% impervious coverage.

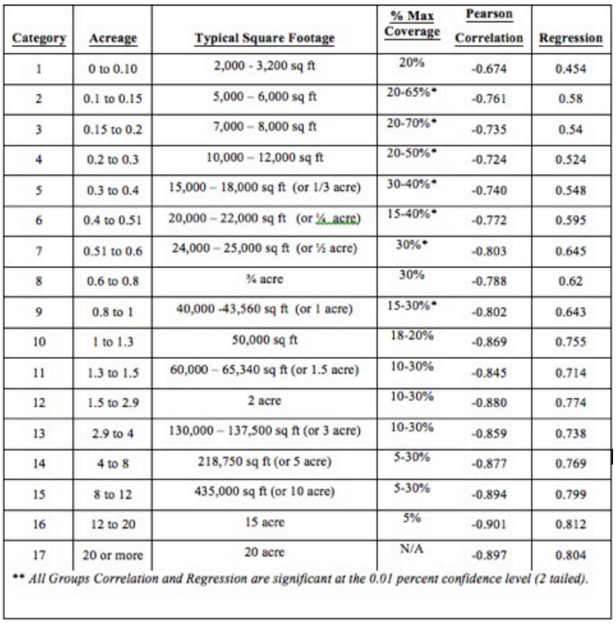
The minimum lot size groupings where less of the Brightness Temperature can be explained by the NDVI value are generally less than one acre lot sizes. In addition, those lot sizes groupings maintain a wide range of maximum impervious coverage between 20% and 70%.

5. Summary and Conclusion

In summary, the results of this research are significant in that the minimum lot size and maximum impervious surface requirements are impacting the strength of the NDVI as an explanatory variable for Brightness Temperature for the municipalities of suburban Somerset County N.J. Further, it is significant findings that the dominant factor driving the SHI variations in the suburban landscape is the presence of vegetation. It will be critical to determine how this finding augments the current local, state, and national policies or reinvigorates them.

While NDVI is a strong explanatory variable; it does not provide information on the percentage of vegetation nor the type of vegetation that is present per parcel. Further research is required to develop a residential form measure to better link land use policy to SHI variations. This research would lead to the development of a tool that can more model changes in percentage tree canopy

Table 3: Relationship & Strength of NDVI as an Explanatory Variable for Brightness Temperature



Category	Acreage	Typical Square Footage	% Max Coverage	Pearson Correlation	Regression
1	0 to 0.10	2,000 - 3,200 sq ft	20%	-0.674	0.454
2	0.1 to 0.15	5,000 – 6,000 sq ft	20-65%*	-0.761	0.58
3	0.15 to 0.2	7,000 – 8,000 sq ft	20-70%*	-0.735	0.54
4	0.2 to 0.3	10,000 – 12,000 sq ft	20-50%*	-0.724	0.524
5	0.3 to 0.4	15,000 – 18,000 sq ft (or 1/3 acre)	30-40%*	-0.740	0.548
6	0.4 to 0.51	20,000 – 22,000 sq ft (or ¼ acre)	15-40%*	-0.772	0.595
7	0.51 to 0.6	24,000 – 25,000 sq ft (or ½ acre)	30%*	-0.803	0.645
8	0.6 to 0.8	¾ acre	30%	-0.788	0.62
9	0.8 to 1	40,000 -43,560 sq ft (or 1 acre)	15-30%*	-0.802	0.643
10	1 to 1.3	50,000 sq ft	18-20%	-0.869	0.755
11	1.3 to 1.5	60,000 – 65,340 sq ft (or 1.5 acre)	10-30%	-0.845	0.714
12	1.5 to 2.9	2 acre	10-30%	-0.880	0.774
13	2.9 to 4	130,000 – 137,500 sq ft (or 3 acre)	10-30%	-0.859	0.738
14	4 to 8	218,750 sq ft (or 5 acre)	5-30%	-0.877	0.769
15	8 to 12	435,000 sq ft (or 10 acre)	5-30%	-0.894	0.799
16	12 to 20	15 acre	5%	-0.901	0.812
17	20 or more	20 acre	N/A	-0.897	0.804

** *All Groups Correlation and Regression are significant at the 0.01 percent confidence level (2 tailed).*

area, lawn area, and the building area, which would include the driveway, and other impervious material to determine the changes in SHI variations. Modeling is needed to support local government's that are reinvigorated to reshape their weather and climate. Moving forward, it is also critical for local government to benchmark their baseline to provide a mechanism to monitor policy changes.

REFERENCES

Bonan G.B. (2000). The microclimates of suburban Colorado (USA) landscape and implications for planning and design. Landscape and Urban Planning, 49, 97-114.

Bornstein, R.D. 1968. Observations of the urban heat island effect in New York City. Journal of Applied Meteorology, 7, 575-582.

Chander G. and B. Markhem. (2003).

Davidson, B. (1967). A summary of New York urban air pollution dynamics research program. Journal of Air Pollution Control, 17, 154-158.

Dhainaut J-F., Y-E. Claessens, C. Ginsburg, and B. Riou. (2004). Unprecedented heat-related deaths during the 2003 heat wave in Paris: consequences on emergency departments, Critical Care, 8, 1-2.

EPA. (2011) Urban Heat Island Program website.

Gaffin, S. R., C. Rosenzweig, R. Khanbilvardi, L. Parshall1, S. Mahani, H. Glickman, R. Goldberg, R.

Blake, R. B. Slosberg, D. Hill. (2007). Variations in New York City's urban heat island strength over time and space. Theoretical and Applied Climatology.

Gedzelman, S.D., S. Austin, R. Cermak, N. Stefano, S. Partridge, S. Quesenberry, and D.A. Robinson (2003) Mesoscale aspects of the urban heat island around New York City. Theoretical Applied Climatology 75 (1-2), 29-42.

Golany, G. 1996. Urban design morphology and thermal performance. Atmospheric Environment, 30, 455-465.

Gottmann, Jean. 1961. Megalopolis: The Urbanized Seaboard of the United States. The MIT Press.

Goward S. N. (1981). Thermal behavior or urban landscapes and the urban heat island. Physical Geography, 1(2),19–33

Hall, Peter. (2002). Cities of Tomorrow, An intellectual History of Urban Planning and Design in the Twentieth Century. Third edition: Blackwell Publishing.

Hartz, D.A., L. Prashad, B.C. Hequist, J. Golden, and A.J. Brazel. (2006). Linking satellite images and hand-held infrared thermography to observed neighborhood climate conditions. Remote Sensing of the Environment, 104, 190-200.

Hayden, Dolores. 2003. Building Suburbia, Greenfields and Urban Growth, 1820 – 2000: Pantheon Books (New York).

Hinkel , Kenneth M., F. E. Nelson, A. E. Klene, and J. H. Bell. (2003). The urban heat island in winter at Barrow, Alaska. International Journal of Climatology 23, 1889–1905.

Hochberg and Tamhane, 1987.

Howard, Ebenezer. (1902). Garden Cities of To-Morrow: Routledge, London.

Klinenberg,E. (2002). Heat Wave: A Social Autopsy of Disasters in Chicago: University of Chicago Press (Chicago).

Landsberg, H. E. (1981). The Urban Climate: National Academy Press, New York.

Levy, John. (2003). Contemporary Urban Planning, Sixth edition: Prentice Hall (Saddle River, NJ).

Lowry, W. (1998). Urban effects on precipitation amount. Progress in Physical Geography 22(4), 477-520.

Lynn, B.H., T.N. Carlson, C. Rosenzweig, R. Goldberg, L. Druyan, J. Cox, S. Gaffin, L. Parshall, and K.

Civerolo. (2009). A modification to the NOAH LSM to simulate heat mitigation strategies in the New York City metropolitan area. J. Appl. Meteorol. Climatol., 48, 199-216.

MacKaye, Benton. (1921). An Appalachian Trail: A Project in Regional Planning, Journal of the American Institute of Architects 9, 325-330.

Mumford, Lewis. (1961). The City in History. Harcourt, Brace & World (New York).

New York City Department of City Planning. (2006). Website accessed: 2007. http://www.nyc.gov/html/dcp/home.html

Nichol, J. E., 1996: High resolution surface temperature patterns related to urban morphology in a tropical city: a satellite-based study. Journal of Applied Meteorology, 35, (1), 135-146

NJGIN (2011) Somerset County GIS Webmapping Application.

Oke, T.R. (1988). Boundary Layer Climates. Routledge, London.

Oke, T.R. (2006). Towards better scientific communication in urban climate. Theoretical Applied Climatology 84, 179–190.

Price, J. (1979). Notes and correspondence: assessment of the urban heat island effect through the use of satellite data. Monthly Weather Review 107, 1554-1557.

Rosenzweig, C. and W.D. Solecki. (2006). Mitigating New York City’s Heat Island with Urban Forestry, Living Roofs, and Light Surfaces. New York City Regional Heat Island Initiative Final Report prepared for The New York State Energy Research and Development Authority.

Rosenzweig, C., W.D. Solecki, L. Parshall, B. Lynn, J. Cox, R. Goldberg, S. Hodges, S. Gaffin, R.B. Slosberg, P. Savio, F. Dunstan, and M. Watson. (2009) Mitigating New York City's heat island: Integrating stakeholder perspectives and scientific evaluation. Bull. Amer. Meteorol. Soc., 90,

Sailor, D. J. and L. Lu. (2004). A top–down methodology for developing diurnal and seasonal anthropogenic heating profiles for urban areas, Atmospheric Environment.

Scobey, David M. (2002). Empire City, The Making and Meaning of the New York City Landscape: Temple University Press, Philadelphia, PA.

Scudder, B. (1965). Diagnosing the mesoscale wind field over an urban area by means of synoptic data. M.S. degree thesis, New York University.

Solecki, WD, C Rosenzweig, L. Parshall, G. Pope, J. Cox, and M. Wiencke. (2003). The Current and Future Urban Heat Island Effect and Potential Mitigation Strategies in the Greater Newark, New Jersey Region, Project Summary.

Stone, B. (2004). Paving over paradise: how land use regulations promote residential imperviousness. Landscape and Urban Planning, 69, 101–113.

Stone, B. and J.M. Norman. (2006). The Role of Urban Spatial Development on Formation of Urban Heat Island. Atmospheric Environment, 40(19), 3561-3573.

Taha, H., Douglas, S., & J. Haney (1997). Mesoscale meteorological and air quality impacts of increased urban albedo and vegetation. Energy and Buildings, 25, 169–177.

USGS. (2011). Landsat 7 ETM+ Program.

Wilson, J. S., Clay, M., Martin, E., Stuckey, D., & Vedder-Risch, K. (2003). Evaluating environmental influences of zoning in urban ecosystems with remote sensing. Remote Sensing of Environment, 86, 303– 321.

Realising a green scenario: Sustainable urban design under a changing climate in Manchester, UK

Gina Cavan and Aleksandra Kazmierczak

1 INTRODUCTION

Climate change impacts associated with increases in temperature are exacerbated in urban areas by the Urban Heat Island effect. The urban heat island is well documented, and can result in temperatures up to 7°C difference between large cities and their surrounding rural areas in the UK (Wilby, 2003). This is due to the process of urbanisation, which replaces vegetated surfaces with impervious built surfaces, which produce, store and re-radiate heat, and also reduce the ability for cooling by evapotranspiration (Whitford et al., 2001). Heat waves can have a disastrous effect on urban populations. Recent examples include the high number of excess deaths associated with heat waves in 2003 across Europe (80,000 excess deaths in twelve European countries, European Commission, 2008); and in England in 2006 (680 excess deaths; European Commission, 2007). Even when heatwaves do not cause loss of life, they are associated with human discomfort (Wilson et al., 2008). Therefore, providing cooling in the urban environment is a high priority for urban planners and designers (Smith and Levermore, 2008).

Urban green space is important for reducing temperatures, via its functions such as cooling through evapotranspiration, storing and reradiating less heat than built surfaces, and through direct shading (Gill, 2006). Its significant cooling effect may limit the impacts of high temperatures associated with climate change on human life, comfort and activities. Recent research indicates that if green cover is increased by town centres and other densely built-up areas, the maximum surface temperatures would be kept at approximately the same level as the 1961-1990 baseline conditions (Gill et al., 2007). Therefore, increasing green space, especially in densely built-up areas is considered to be a valuable adaptation response in order to reduce the threat of high temperatures to human health and comfort.

This paper investigates the use of vegetation in order to influence the microclimate of an urban area. It focuses on climate projections and modelling of green space cover under different development scenarios, and the barriers and opportunities in realizing the best scenario. This research is being undertaken for EcoCities project, which aims to provide the Greater Manchester conurbation with a climate change adaptation blueprint by the end of 2011.

2 STUDY AREA

Greater Manchester is a post-industrial conurbation situated in the North West of England, with a population of over 2.5 million. The conurbation is composed of ten local authorities: Bury, Bolton, Oldham, Rochdale, Stockport, Tameside, Trafford and Wigan; and includes the cities of Salford and Manchester (Fig. 1). This study focuses on the Oxford Road Corridor area (hereafter referred to as The Corridor), a major private and public transport link extending from

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Figure 1: Location of The Corridor in Greater Manchester, UK. Base map is © Crown Copyright/database right (2010). An Ordnance Survey/EDINA supplied service.

the city centre to south Manchester, covering and area of 2.73km2 (Fig. 1).

The Corridor is a strategically important economic development area, containing 37,000 workers (12% of the city's workforce), supports a wide range of cultural attractions, and its envisaged growth is to be propelled by the combined forces of the educational and health institutions, who have committed to a £1 billion investment programme. The core principles of The Corridor Partnership, established between the major landowners in the area, are identified in a Strategic Development Framework for the area and focus on maximising the opportunities arising from current and planned development and predicted economic growth along The Corridor and supporting growth through improvements in infrastructure. Emphasis is also placed on improving the environmental quality of Oxford Road by reducing pollution, emissions and noise, and creating a sustainable public realm, which would encourage walking, cycling and use of public transport throughout the area (Manchester City South Partnership, 2009).

Currently, green space is not a prominent feature of the area, with two parks (Whitworth and Grosvenor), small areas of vegetation associated with buildings, and a small number of street trees. Whilst increasing green space is not explicitly a principle of The Corridor Partnership, it can be linked to improving environmental quality in the area and the public realm. Also, the Strategic Development Framework acknowledges the links between greening the urban environment and strengthening the demand for retail and leisure. In particular, tree planting along the main transport axis, Oxford Road, is seen as an opportunity to soften the otherwise built-up landscape and to make the area healthier and more sustainable (Manchester City South Strategic Partnership, 2009).

3 METHODOLOGY

The research followed three main stages. Firstly, an assessment of the current land cover characteristics of the Corridor was undertaken. The land cover in The Corridor was categorised into nine surface cover types (building, other impervious surface, tree, shrub, mown grass, rough grass, cultivated, water and bare soil/gravel) using Ordnance Survey MasterMap data and aerial photography of Manchester (for further information, see Kazmierczak et al., 2010). Interpretation of aerial photography enabled identification of the surfaces that could potentially be fully or partially greened in the future. These included flat roofs of buildings; car parks, courtyards and other large sealed surfaces; and roads where street trees could be planted. This informed the construction of three different future development scenarios (deep green and high development), indicating how design and development of the area could result in different trajectories of land cover characteristics in the future.

Secondly, an energy exchange model was run to analyse the current and future surface temperatures in The Corridor, under the current situation and for two development scenarios. Surface temperature is thought to be an effective indicator for modelling energy exchange in the urban environment (Whitford et al., 2001; Gill et al., 2007). The energy exchange model developed by Tso (1990; 1991) is based on an energy balance equation, and provides outputs of maximum surface temperature. A modified version of this model for Greater Manchester (Gill, 2006) was used to model the baseline and future projected surface temperature for The Corridor. The impact of climate change on surface temperatures was incorporated through input of the latest climate change projections information, using the Weather Generator (WG), available from the UK Climate Projections (UKCP09) user interface. The surface temperature model was run for the baseline 1961-1990 period and 2050s low and high emissions scenarios (equivalent to the IPCC B1 and A1FI scenarios) (for further information, see Kazmierczak et al., 2010).

Thirdly, structured interviews were carried out with the Corridor Partnership Board (Table 1) in September-October 2010 to investigate views on the impact of climate change in the Corridor and identify the strengths, weaknesses, opportunities and threats of realising the deep green scenario. Strengths and weaknesses were understood as the current issues within the Corridor which affect the delivery of the scenario; threats and opportunities were associated with external or future impacts. The interviewees were also asked which specific functions and benefits of green

Table 1: Organisations forming the Corridor Partnership Board

Sector	Organisation
Public	Manchester City Council
	North West Development Agency
	Central Manchester University Hospitals NHS Foundation Trust
Pseudo-public and third sector	University of Manchester
	Manchester Metropolitan University
	Cornerhouse (centre for contemporary visual arts and film)
Private sector	Manchester Science Park
	ARUP
	Bruntwood
Other	Chief Executive of the Corridor

infrastructure are important in the Corridor, and could help in the delivery of the deep green scenario. Two group interviews were carried out with the representatives of Manchester city council, involving two respondents on each occasion. In total, 13 interviewees were involved in this research. The questionnaires were audio-recorded, transcribed and coded using NVivo software.

4 RESULTS AND DISCUSSION

4.1 Current and future land cover in the corridor

Analysis of the current surface cover types in The Corridor revealed that over 80% of the area is built up (Table 2). The evapotranspiring surfaces are mainly comprised of trees and mown grass. Analysis of aerial photography was undertaken to determine the areas in The Corridor that could be greened, or conversely, be developed. This revealed that of the surfaces that could be greened: there are 161 flat roofs within The Corridor, amounting to 8.171%, and large sealed surfaces (excluding roads) and carparks represent 7.884% of the area. Formal green space (in Grosvenor and Whitworth Parks), which could not be developed without significant amendments to the open space regulations in Manchester, covered just over 3% of the area. This information enabled creation of the three future development scenarios:

Business as usual – this scenario assumes that the future ratio of green space to buildings and roads will remain the same as the current situation;

Table 2: Current proportion of different land cover types in The Corridor

Surface cover category	**Area (%)**	**Surface cover type**	**Area (%)**
Built up	82.955	Buildings	27.100
		Other Impervious	55.855
Evapotranspiring	15.227	Mown Grass	5.863
		Rough Grass	0.754
		Shrubs	0.450
		Trees	7.421
		Water	0.739
		Cultivated	0.000
Bare soil	1.818	Bare soil	1.818

Deep green scenario – this scenario assumes that all flat roofs are greened by 100%, large sealed surfaces and carparks are greened by 50%, and trees are planted along roads and streets (resulting in greening by 30%); and,

High development scenario – this scenario assumes that all green space and bare soil, with the exception of Whitworth and Grosvenor Parks and existing open water bodies, are replaced by buildings or other impervious surfaces.

The resulting land cover characteristics associated with each of the three scenarios are shown in Fig 2. This indicates significant differences between the scenarios of future provision of green space. Whilst under the deep green scenario the green and blue space cover increases by 130%, under the high development scenario it is four times smaller than the current provision.

4.2 Modelling current and future surface temperatures in the corridor

Climate projections for the 2050s (2040-2069) generated for The Corridor area suggest that there will be a significant increase in temperatures across all seasons. The mean summer temperature is likely to increase from the 1961-90 baseline by 1.06-3.65 °C under the low emissions scenario and by 1.6-4.67 °C under the high emissions scenario (Table 3). Warming is greatest

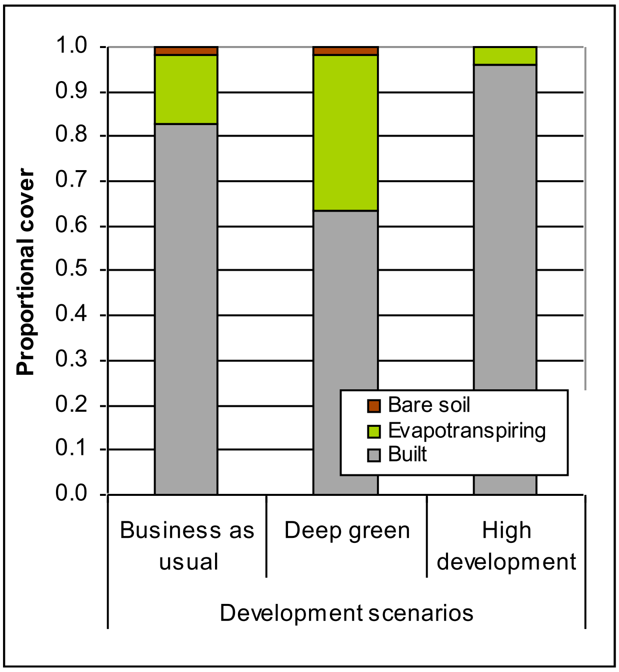

Figure 2: Surface cover of the three future development scenarios of The Corridor

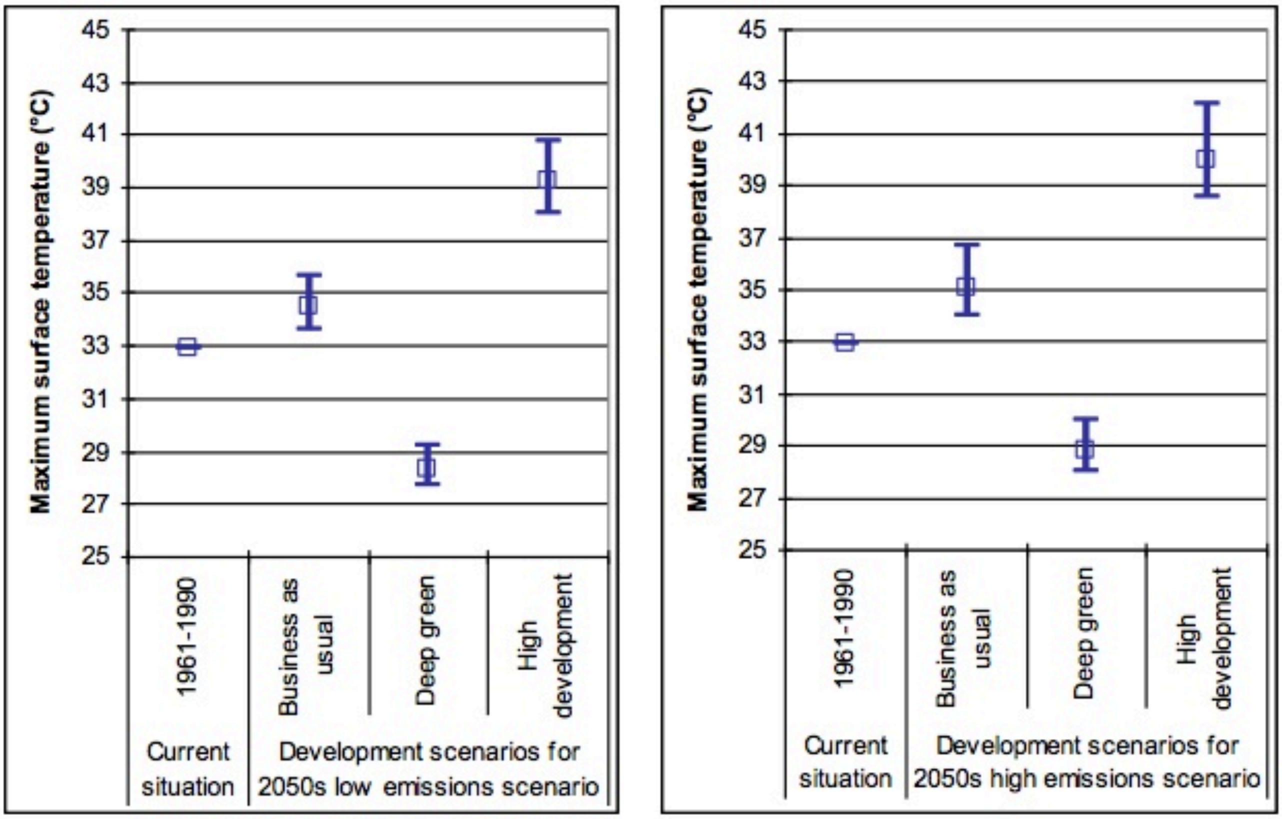

Figure 3: Impact of development scenarios on maximum surface temperatures for the 98th percentile summer day for the 2050s (a) low; and, (b) high; emissions scenarios for The Corridor.

Table 3: Changes in summer and winter temperatures from the UKCP09 WG projections for The Corridor area. Changes from the 1961-90 baseline are shown for the 2050s low and high emissions scenarios for the 10th, 50th and 90th percentiles.

Temperature (°C)	**1961-1990 baseline**	**2050s Low Emissions Scenario (B1)**			**2050s High Emissions Scenario (A1FI)**		
		Percentile			Percentile		
		10th	50th	90th	10th	50th	90th
Mean winter temperature	4.33	1.14	2.00	3.31	1.89	2.58	4.18
Mean summer temperature	15.79	1.06	2.17	3.65	1.60	2.86	4.67
Daily maximum winter temperature	6.88	1.04	2.02	3.26	1.75	2.49	4.04
Daily maximum summer temperature	19.53	0.93	2.57	4.21	1.72	3.20	5.40

during the daytime in summer, reflected by the projected increase in the summer mean daily maximum temperature, which is unlikely to be more than 4.21°C above the baseline under the low emissions scenario; and unlikely to be more than 5.4°C increase under the high emissions scenario.

Results from the energy exchange model indicate that the business as usual and high development scenarios result in increased surface temperatures in The Corridor compared to the baseline 1961-1990 period (Fig. 3). The business as usual scenario illustrates that climate change alone will increase the baseline surface temperature experienced approximately two days per summer by between 0.7-2.7 ºC under the low emissions scenario, and by between 1.1-3.7 ºC under the high emissions scenario. In particular, the high development scenario causes surface temperatures to increase by around 5.1-7.8 ºC under the low emissions scenario, and by between

5.6-9.2 °C under the high emissions scenario. In contrast, provision of additional green space under the deep green scenario causes the surface temperatures to decrease by between -4.9 °C and -3.0 °C under the high emissions scenario, and by between -5.2 °C and -3.8 °C under the low emissions scenario. Therefore, even with increasing air temperatures resulting from climate change (Table 3), provision of a considerable amount of green space can decrease the surface temperatures in relation to the baseline climate conditions.

4.3 Implementing the scenario in practice: barriers and opportunities

This section describes the responses from interviewers regarding: their perceptions of the modeling results; strengths, weaknesses, opportunities and threats (SWOT) of the deep green scenario; and, the way forward in order to realise the green scenario.

Perception of the modelling results of surface temperature under different development scenarios: Presentation of the research results was a useful exercise as it increased the participants' awareness of climate change and the issues and problems associated with it:

Interviewee 5: "*I think it was a bit of a trigger point to start thinking about climate change, design of buildings, greening, and [how to] join that together.*"

The majority of the respondents considered the increase in temperatures associated with climate change as a significant impact, mainly due to the density of development and the number of people working in The Corridor. It was observed that there may be conflicts between adaptation and mitigation strategies, which may also impact on the way that we use our cities:

Interviewee 10: "*The temperature changes would cause a significant change in the working environment, so we all fit air conditioning or something similar which is going to add to energy consumption, so we are in a vicious circle then.*"

Interviewee 3: "*30 degrees – it's like Phoenix, Arizona. They cope, but they cope by having expensive air conditioning and people don't go out much during the day (…) It's like arriving in the city that's had a nuclear bomb gone off – the buildings have not been harmed but there is no people.*"

Table 4: SWOT analysis for achieving the deep green scenario

Strengths (current, local)	**Weaknesses (current, local)**
• Awareness of environmental issues, including climate change • GI closely aligned with the priorities of the corridor and individual organisations • A number of ongoing greening initiatives • Recognition of multiple benefits of green infrastructure • Partnership guided by a strategy focused on greening • Recognition that development and greening are not mutually exclusive • Land ownership: limited number of parties • Some opportunities in physical environment	• Need for upfront investment and long payback time • Limited planning powers • Limited green space currently and no space for widespread greening • Limited opportunity for common investment • Practical issues associated with installation and maintenance
Opportunities (higher level, future)	**Threats (higher level, future)**
• Involvement/leadership of the city council • National initiatives for funding and subsidising green infrastructure • Anticipated future lifestyle and technological changes • Learning, communication and exchange of experiences • Incorporation of greening in planning and development	• Planning system nationally driven, focused on economic benefits rather than the environmental agenda • Negative perceptions of climate change and green space agenda • Financial: spending cuts in public sector • Managing green space under changing climate for high functionality

SWOT analysis for achieving the deep green scenario: Table 4 outlines the strengths, weaknesses, opportunities and threats of achieving the deep green scenario. It is notable that the strengths and weaknesses describe the current situation within the Corridor, whilst the opportunities and threats relate to external influences and future possibilities.

Strengths: An important prerequisite for adaptive actions is recognising that climate change is happening. A major strength is that the partnership members all perceive climate change to be a significant issue, e.g. "*I do believe that the issue of climate change is recognised by the group, and therefore that there is the desire to make something happen*" (Interviewee 10).

The Partnership strategic development framework supports greening and the commitment to greening the Corridor was illustrated through reference to examples of projects and initiatives in the area. The particular benefits of green infrastructure recognised by the interviewees related to quality of place and economic benefits, such as promoting a competitive edge, e.g. "*One of the distinguishing features of this part of the city might be that from being a fairly arid urban environment it becomes very green and certainly it is being promoted for that as one of the core values of what we are trying to do. I think that could be quite a selling point in the distinguishing factor in the future*" (Interviewee 13).

The low number of land owners in the area, was considered to be a strength that could potentially make implementation easier through partnership working with a coherent strategy, and the support of Manchester City Council was seen as crucial. Peer pressure within the partnership was also seen as an important driving factor: "*If you want to be part of the clan then you have to be seen doing it this way*" (Interviewee 13).

Finally, the physical environment in the Corridor was viewed as a strength, as whilst green space is currently limited: "*there are also some bleak areas that could be developed and the city council needs, from the planning perspective, to earmark those bleak areas for green spaces*" (Interviewee 7).

Weaknesses: Financial issues were considered to be the main weaknesses to achieving the deep green scenario. In addition, the uncertainty about the economic benefits of GI, and the perception that GI was not a necessary measure, were seen as obstacles in justifying investments. The long payback time of green spaces, in particular green roofs, was considered to be another financial obstacle.

Interviewee 9: "*It is about upfront capital investment and in difficult times it is very hard to justify that upfront.*"

Interviewee 8: "*I don't think that they [green spaces] are… absolutely business critical. I don't think people are going to die or businesses are going to fail if you are not going to do them.*"

Also, there was an agreement about limited opportunities for working together in terms of common investment into green solutions, due to the individual character of financial and governance structures and timeframes in the partnership institutions.

The interviewees recognised that the planning system has a limited influence over the provision of green space in the Corridor, due to the large area being in private ownership, and already developed.

However, the Corridor Partnership as such does not possess planning powers which could be used to enforce the implementation of the green scenario.

Finally, other weaknesses included a number of maintenance issues with green space, such as the negative impact of trees on plumbing and utilities, recognised technical difficulties hindering widespread construction of green roofs, and grass being impractical.

Opportunities: The main opportunity for implementation of the green scenario in practice was the potential of strong involvement of the city planners, in addition to emerging national initiatives.

Interviewees identified factors that may provide more opportunities for greening, including: changes in transport (fewer car parks and roads needed); fewer people working in city centres due to technological change and better ICT infrastructure; and ongoing scientific progress in implementation of green roofs.

Another opportunity was seen in exchange of experiences – both within the Corridor, and outside it, including internationally, e.g. "*I am impressed about the way their [Spanish] plazas are organised, their public spaces, their play spaces, how they care for and protect them, and keep up the standards (…). We do have to copy other European cities to develop these open spaces*" (Interviewee 7). In particular, the role of big public institutions as exemplars was emphasised. Communication of the need to provide green infrastructure to the general public, and in particular to young people, was also considered to be important.

Finally, some mechanisms for implementation of the greening in development were noted as opportunities. These included planning greening alongside maintenance and development of infrastructure and building and inclusion of requirements for greening in search for development partners, e.g. "*Any tendering process – so when the institutions are looking for a development partner, they can require people to work with them along these sorts of guidelines*" (Interviewee 9).

<u>Threats:</u> Deficiencies in the British planning system in relation to greening was viewed as a major threat as the environmental agenda is largely separated from economic and development aims, which tend to dominate priorities e.g. "*Planning and development at the moment are very much driven by the economic benefits that investment brings, and certainly the city council, its thinking, is very strongly about economic regeneration and development and wealth creation*" (Interviewee 5). The current program of spending cuts in the public sector introduced by the British government was also viewed to be a potential threat.

The interviewees also noted limited options for local authorities to develop and implement local regulations or incentive schemes for greenspace, as such issues are regulated centrally. This, combined with the economic focus may force planners to be unsympathetic towards the greening agenda.

People's life choices and perceptions were seen as a potentially significant threat. It was noted that a proportion of the population remains sceptical about climate change adaptation and is dependent on the car, perpetuating the need for car parks and wide roads. Furthermore, the interviewees reflected on the lack of appreciation of public greenery in British cities, e.g. "*I do see that business of attitudes of people being a significant barrier (…) If anybody tries planting saplings round [a location] people would come and pull them all out on Saturday nights because they've had too much beer*" (Interviewee 8).

Finally, the issue of maintaining the functionality of green space in the future under the changing climate was considered to be a threat to the success of the deep green scenario, e.g. "*It may be more difficult to maintain urban green spaces with the same level of functionality that they have, so you may get more situations when the grass gets browned off, or if the trees get heat-stresses, then you may get premature leaf drop and things like that*" (Interviewee 6).

<u>The way forward:</u> A number of external and internal measures were suggested for the way forward to achieving the deep green scenario. These are summarised as:

External measures:

Using a combination of education, enforcement and incentivisation in relation to green adaptation options to support the behavioural shift among public sector, businesses and the general public;

Need for research: economic value of green space; climate-resilient plants; and,

Removing the obstacles for shared investment (e.g. the VAT penalty).

Internal measures:

Working in partnership: city leadership; large institutions leading by example; coherent strategy on green space; and,

Emphasis on green scenario in planning and land development: protecting current green space; finding opportunities for more; building higher to save space; including water capturing and storage systems in plans; discouraging car use.

5 CONCLUSION

The results of this study suggest that an increase in greenspace within The Corridor, within the framework dictated by the existing development, could significantly ameliorate rising temperatures associated with climate change and the urban heat island effect. Further, an increase in human comfort and quality of life and the decrease in a number of days when artificial cooling is required could be significant incentives for land owners and developers to invest in green spaces within their developments.

The possibility for realisation of the deep green scenario was discussed with the Corridor Partnership. Results suggest that there is a good chance for implementation of some elements of the deep green scenario: the partners all perceive climate change to be a significant issue, there are some foundations in the existing development strategy, the partners have very positive perceptions of the benefits of green space, and there is an array of examples of ongoing and planned initiatives which include enhancement of green space.

The main threats and weaknesses highlighted from interviews were associated with financial and economic issues, as well as the dependence of the Partnership on national regulations. The current emphasis on localism in the British planning system could potentially support governance at the partnership level.

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REFERENCES

European Commission, "The 2003 European heatwave", 2008,

http://ec.europa.eu/health/ph_information/dissemination/unexpected/unexpected_1_en.htm.

European Commission, "The 2006 European heatwave", 2007,

http://ec.europa.eu/health/ph_information/dissemination/unexpected/unexpected_9_en.htm.

Gill S.E., "Climate Change and Urban Greenspace," Unpublished PhD thesis, University of Manchester, 2006, http://www.ginw.co.uk/resources/Susannah_PhD_Thesis_full_final.pdf.

Gill S., Handley J., Ennos R. and Pauleit S., 2007. "Adapting cities for climate change: the role of the green infrastructure," Built Environment, Vol. 33, No.1 (2007), pp.115-133.

Jones P.D., Kilsby C G., Harpham C., Glenis V. and Burton, A., "UK Climate Projections science report: Projections of future daily climate for the UK from the Weather Generator," University of Newcastle, UK, 2009.

Kazmierczak, A. Cavan, G. Carter, J. Handley, J. and Guy, S., "Deep green or white hot? The future of the Oxford Road Corridor in Manchester, UK," RICS, COBRA, 2010, London, 2010. ISBN: 9781842196199, http://www.rics.org/site/scripts/download_info.aspx?fileID=7960&categoryID=720.

Manchester City South Partnership, "Strategic Development Framework," Manchester City South Partnership, Manchester, 2009.

Smith C. and Levermore G., "Designing urban spaces and buildings to improve sustainability and quality of life in a warmer world," Energy Policy, Vol. 36, No.12 (2008), pp.4558-4562.

Tso C.P., Chan B.K. and Hashim M.A., "An improvement to the basic energy balance model for urban thermal environment analysis," Energy and Buildings, Vol. 14, No. 2 (1990), pp.143-152.

Tso C.P., Chan B.K. and Hashim M.A., "Analytical solutions to the near-neutral atmospheric surface energy balance with and without heat storage for urban climatological studies," Journal of Applied Meteorology, Vol. 30, No. 4 (1991), pp.413-424.

Whitford V., Ennos A.R. and Handley, J., "“City form and natural process” - indicators for the

ecological performance of urban areas and their application to Merseyside, UK," Landscape and Urban Planning, Vol. 57, No. 2 (2001), pp. 91-103.

Wilby R.L., "Past and projected trends in London’s urban heat island," Weather, Vol. 58 (2003) pp.251-260.

Wilson E., Nicol F., Nanayakkara L. and Ueberjahn-Tritta A., "Public urban open space and human thermal comfort: the implications of alternative climate change and socio-economic scenarios," Journal of Environmental Policy and Planning, Vol. 10 (2008), pp.31-45.

Implementation of Urban Climatology in City Planning in the City of Stuttgart

Ulrich Reuter

1. Introduction

Stuttgart is the capital city of the federal state Baden-Württemberg in the southern part of Germany. With nearly 600 000 total population it is the centre of a metropolitan region of about 2,7 Million people. The total area covers 207 km2 with 50 % settlement and 24 % forest.

Not without reason, the characteristics of the Stuttgart climate and air hygiene have long been the focus of attention. Indeed the favourable location of Stuttgart, in terms of landscape and climate, masks certain problematical aspects of its urban climate.

Lots of sunshine and mild weather characterise the climate around Stuttgart. In the City the annual average temperature is 10 degrees Celsius. On the Filderhochfläche (Filder plateau) on the Southern border of the city, the average air temperature is 1,4° lower. There is a strong diversity in the climate and local variations in the individual districts. The development of local climates also benefits from the relatively weak wind movements, a condition typical for Stuttgart with its position between the Black Forest, the Schwäbische Wald and the Schwäbische Alb. The annual mean value in Stuttgart is only 1,5 m/sec (at the airport 2,4 m/sec). With 20 – 30 %, the wind blows predominantly in a South-Westerly direction.

2. Urban Climatology in Stuttgart - Short historical overview

In 1938, Stuttgart City Council decided to appoint a meteorological graduate to perform studies of the climate conditions and their relationship to urban development.

The creation of “urban climatology” as a field of study needs to be placed in context, particularly against the background of the complex topographical situation of the City of Stuttgart and the lack of adequate air exchange which prevailed here. Thermal stress and sensitivity to the effects of heat are common in combination with the mild climate of a wine-growing region. Stuttgart’s second handicap in respect of climate and air hygiene is due to its lack of wind, namely the episodic rise in air pollution.

Systematic measurements of air pollution in Stuttgart have been performed since as long ago as 1965.

In the early seventies, the use of infrared thermography for urban climatology investigations was researched and implemented in practice for the first time as part of a special planning process. On the basis of experience gained during this process, comprehensive infrared thermographic measurement flights were commissioned over the entire urban area several times.

During the early seventies, the term “environmental protection” became an ever more familiar part of the language. The German Federal Environment Office came into being and important additions were made to environmental legislation. The German Immission Control Act came into force in 1974. Alongside plant-specific regulations, this also sets out district-related regulations, and in Article 50 formulates a significant principle of environmental protection as it relates to urban planning.

At the same time, interest in questions of urban climatology was also on the increase. 1977 saw the validation of a new draft of the Federal Construction Act, article 1 of which sets out the objectives and principles of construction management planning, which include consideration of environmental concerns, ruling that the natural basis for human existence, in particular the soil, climate and air, be maintained and safeguarded. This raised "air and climate" to the status of planning factors (Federal German Building Code, latest version 2004).

A first "multiple-component air measurement station" was successfully established to measure sulphur dioxide, carbon monoxide, dust content and dust fallout as well as wind direction and wind speed in 1977 over a period of one year. Further immission stations followed.

The first Climate Atlas for the region of Stuttgart was published 1992 (Nachbarschaftsverband Stuttgart, 1992). For the first time, the results achieved permitted comprehensive climate overview maps to be produced of the territory of the associated municipalities. Added to these were coordinated climate analysis maps and so-called planning indication maps.

As an updating of the climate atlas based on GIS, the climate atlas for the region of Stuttgart has been available in digital form since May 2008 (Verband Region Stuttgart, 2008).

In 1990, the legal outline conditions surrounding immission control in the assessment of air pollutant immissions were amended. Based on the scope offered by this change for traffic planning, traffic guidance and traffic restricting measures, an initial Air Pollution Control Plan was issued for Stuttgart.

With the city's accession to the Climate Alliance of European Cities in 1995, the work of the Section of Urban Climatology was extended to include the new field of climate protection. In this context, a resolution was adopted to develop a climate protection program (KLIKS) for Stuttgart (more information: City of Stuttgart, 2009) and meanwhile a climate change adaptation program.

Many other investigations were taken as the basis of an "Urban climate information system". This information system was also given the equally pioneering name of "Urban climate21" (City of Stuttgart, actual version 2008). Through the integration of additional system components, this system has continuously evolved to its present-day development status.

The advent of the new century saw the implementation of major changes in the field of air pollution control. As a result of the new EU Directive on Air Quality, a number of binding stipulations were defined on the evaluation and monitoring of air quality. An air pollution control / action plan set up in December 2005 by the District Administration of Stuttgart encompasses a total of 36 individual measures. It was actualized in 2010.

3. Tools

To join climatic data and information on air pollution measurements are done at fixed points and mobile. In several years the surface temperature of the Stuttgart region was measured from airplane by infrared thermography. This gives a good overview on the spatial distribution and intensity of the urban heat island. Balloon measurements were carried out to investigate the vertical structure of the atmosphere in Stuttgart. Finally a lot of calculations are done concerning climatic aspects, such as local cold air flow and heat stress, and concerning the air pollution situation.

From all these basic information a city and region wide climate atlas was constructed.

The section carried out a large-scale climate analysis for the territory of the associated municipalities and adjacent regions and published the results in the first Climate atlas in 1992 (Nachbarschaftsverband Stuttgart, 1992).

Since planning-related statements refer to specific areas, Nachbarschaftsverband Stuttgart, the use of maps as an informational basis is recommended. Maps in this context are a very significant tool for the planner, and are also a meaningful method of communicating information for politicians and the interested public. As such, spatially-related cartographic representations are necessary for attaining climatic and air-hygienic goals.

The example of the Climate Atlas produced by the Stuttgart Regional Federation for the territory of the federation and the bordering parts of the Middle Neckar Region shows how the concerns of climate and air can be incorporated into cartographic representations for land-use planning.

The study results are summarized and depicted in analysis maps of 1:20,000 scale, which corresponds to that of land-use plans.

One of the main features of the maps are Climatopes. Climatopes describe geographic areas with similar microclimatic characteristics.

The map also contains information on areas with cold air production and cold air flow.

Also depicted are cold air blockage areas, narrow sections of valleys, winds descending from slopes, mountain and valley winds, and air induction passages for regional winds, along with data for air pollution.

As an additional step, evaluated maps were produced with climatic and air-hygienic recommendations for planning.

The goal of the planning recommendations is first and foremost to motivate the planner towards a stronger consideration of climatic criteria. As such, a planning project should incorporate the standards of the "Planning Recommendations" map.

A map with recommendations for planning contains an integrated assessment of the material represented in the climate analysis map as it relates to concerns relevant in planning. The symbols give recommendations as to the sensitivity of certain land areas to changes in land use, from which climatically-grounded conditions

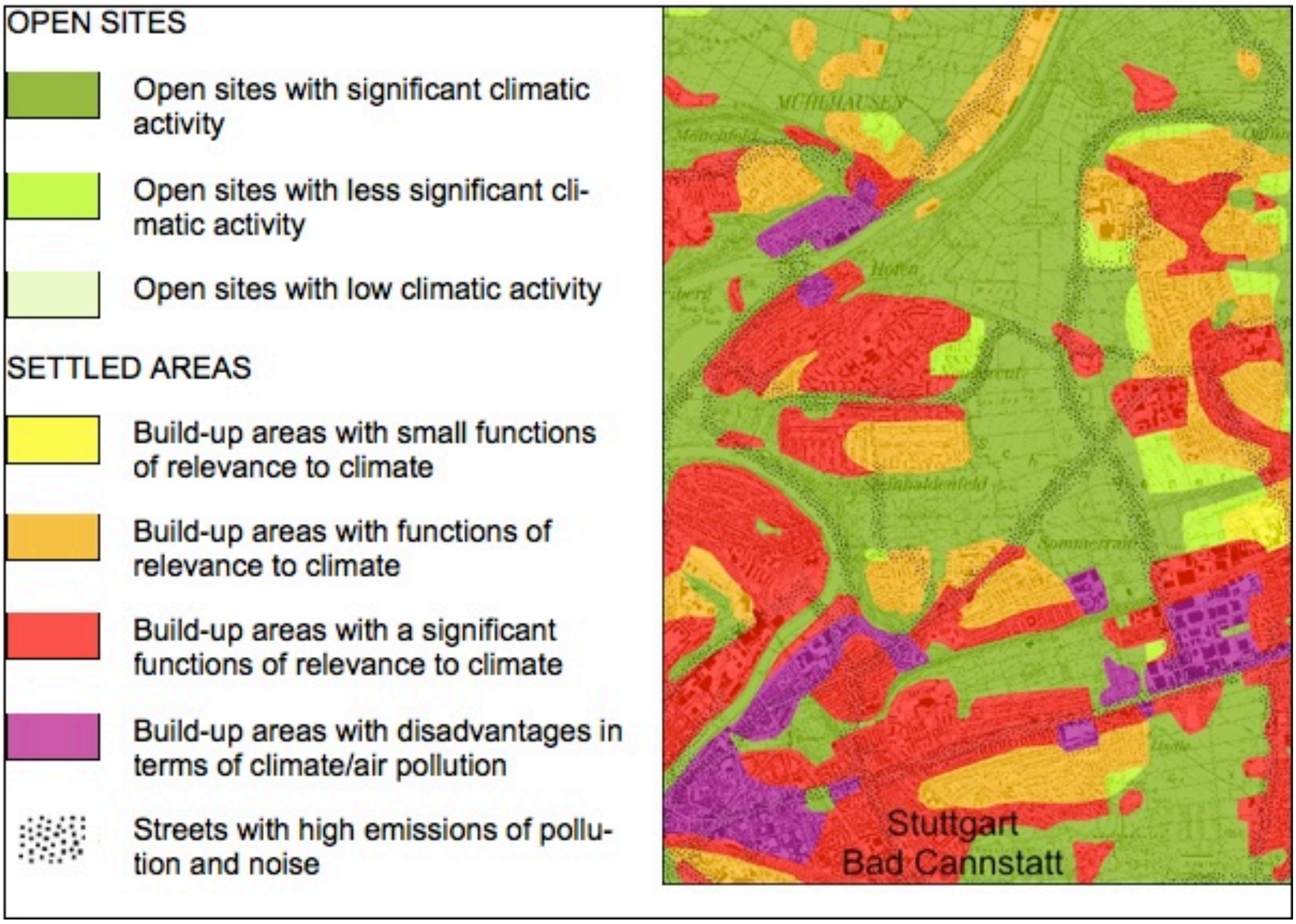


Figure 1: Example of map with planning recommendations

and measures can be derived in the context of planning and zoning.

As an updating in 2008 the Climate Atlas Region Stuttgart was published. It is based on GIS and includes the area of the region of Stuttgart in a size of 3654 km2 (Verband Region Stuttgart, 2008).

Additionally all available information were incorporated into a DVD “Urban Climate 21” (City of Stuttgart,2008), which includes basic materials for urban climate and for the planning, prepared by Office for Environmental Protection, Department for Urban Climatology of the Stuttgart city.

The DVD “Urban climate 21” contains more than 300 areal and line datasets, more than 100 print datasets, more than 400 textfiles and 1000 photos, pictures and figures. The DVD is a prominent source about the urban climate of Stuttgart.

More generalised a climate booklet for urban development was made by the Department for Urban Climatology, which is edited by the Ministry of the State of Baden-Württem-berg. It contains many basic information on urban climate and how to implement these aspects in urban planning (Ministry of Economic Affairs, online version 2004).

4. Implementing Urban Climate in Urban Planning

There are many possibilities to implement urban climate in urban planning (City of Stuttgart, 2010).

4.1 Urban Green

Green belt policy and green space planning are the most promising areas of municipal influence in respect of their impact on urban climatology and climate protection. The provision of green areas, forested areas and open spaces benefits the urban climate and the appeal of the city in equal measure and can help to mitigate urban climatological deficits.

As planning objectives outlined by the Land Use Plan for built-up areas, green corridors and green networks constitute important elements of planning for optimization of the urban climate.

Stuttgart has plenty of experience in the construction of tram lines with grassed-over tracks. This applies not only to planning and construction, but also long-term maintenance.

Figure 2: Fresh air corridor “Schelmenäcker” (Aerial photo: City of Stuttgart, Surveying Office)

There are already around 35,000 trees planted alongside Stuttgart's streets. Almost all traffic islands have already been greened over.

Roof greening can also be set out as a legal requirement in the development plan.

4.2 Fresh air corridors

Topographic structures such as stream and meadow valleys provide natural green belts which at the same time represent preferred pathways for ventilation.

Keeping these free of encroachment by buildings does not necessitate a great deal of persuasion, given that aspects of landscape and nature conservation also support the urban climatology arguments.

The course is set in favour of retaining undeveloped fresh air corridors within the framework of the Land Use Plan, in which the structures to be developed are already set out in the overriding regional plan by the depicted green belts and green divides.

For example in the Schelmenäcker area of Stuttgart Feuerbach, plans were presented for the extension of an existing residential building area near a hillside zone reaching down from the woodland-covered Lemberg mountain to the centre of the town. The plans envisaged development through the corridor leading up to the hillside. A strip just 7 metres wide would have remained undeveloped from the hillside zone in the form of roadside greenery.

The urban climatological arguments put forward fell on receptive ears in the urban planning department, and finally resulted in a completely changed development concept with a wide fresh air corridor of around 100 m in width.

4.3 Outline plan

The Hillside Development Outline Plan (Rahmenplan Halbhöhenlagen City of Stuttgart, 2008) is a planning instrument which on the basis of statements relating to environmental protection (soil, climate, free space, local recreation, landscape) defines areas comprising a combination of cold air channels and green belts which consequently depict the environmental quality of Stuttgart's hillsides.

The climate-active areas of vegetation on the hillsides which are not used for building help support thermally induced air exchange close to the ground, which contributes towards producing improved air hygiene conditions in Stuttgart in the form of nightly downslope winds and nightly cooling.

Both in terms of wind dynamics and also thermally, extended building development in the hillside areas would impact negatively on the nightly downflow of cold air.

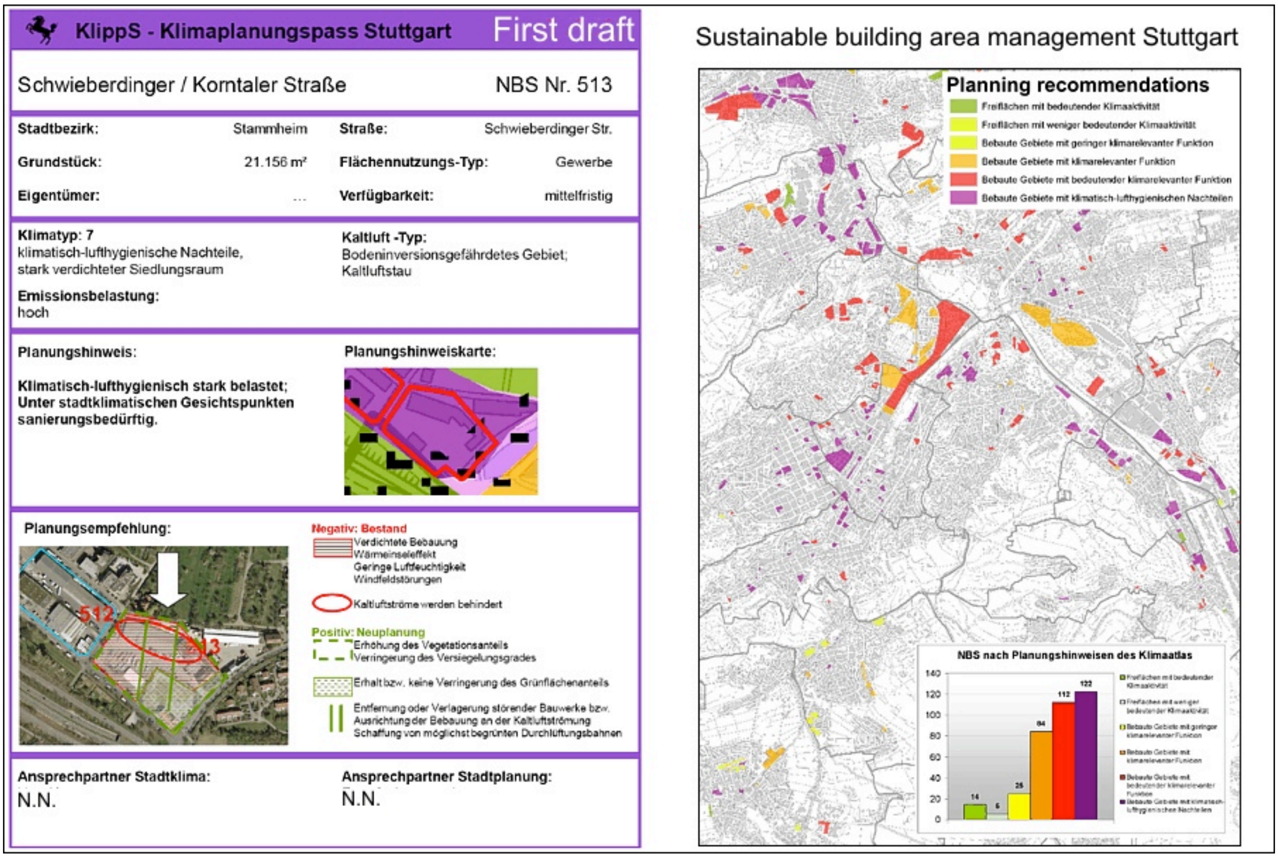
At the same time, the outline plan also takes consideration of the fact that isolated urban climatological assessments of minor individual building projects encounter problems of scale if the changes anticipated as a result of the building project have be described in quantitative terms.

4.4 Sustainable building land management

Taken overall, greater concentration of dense inner city development in favour of larger cohesive free spaces and cold air generating areas should be greeted in principle as a positive development. Despite this it is important to work towards a climate-optimized concentration of urban structures without intensifying the heat island effect.

To achieve this type of “qualified density”, urban development requires suitable strategic alignment. This exists on principle in Stuttgart in the form of the Stuttgart inner city development model (SIM) which describes a “dual inner city development”.

A software tool which can be used for successful mobilization of existing brownfield potential (Sustainable Brownfield Development Stuttgart, German abbreviation NBS) makes an important contribution here. NBS, developed within the framework of a model project, permits



KlippS - Klimaplanungspass Stuttgart First draft

Schwieberdinger / Korntaler Straße NBS Nr. 513

Stadtbezirk:	Stammheim	**Straße:**	Schwieberdinger Str.
Grundstück:	21.156 m²	**Flächennutzungs-Typ:**	Gewerbe
Eigentümer:	...	**Verfügbarkeit:**	mittelfristig

Klimatyp: 7
klimatisch-lufthygienische Nachteile,
stark verdichteter Siedlungsraum

Emissionsbelastung:
hoch

Kaltluft -Typ:
Bodeninversionsgefährdetes Gebiet;
Kaltluftstau

Planungshinweis:

Klimatisch-lufthygienisch stark belastet; Unter stadtklimatischen Gesichtspunkten sanierungsbedürftig.

Planungshinweiskarte:

Planungsempfehlung:

Ansprechpartner Stadtklima:
N.N.

Ansprechpartner Stadtplanung:
N.N.

Figure 3: NBS and Climate planning document Stuttgart, first draft, A.-K. Keller, City planning office Stuttgart.

comprehensive computer-aided analysis of existing brownfield sites, documentation and regular tracking of existing fallow land, gaps between buildings and further concentration potential. In a next step climate recommendations will be integrated in NBS (climate planning document Stuttgart, KLIPPS).

5. Conclusions

Taking into account urban climatology in urban planning has a long tradition in Stuttgart. It is an important topic, which is fixed in the German Federal Building Code.

Stuttgarts practices can very well serve as a model for other cities in the world.

Facing the global climate change urban climatology is getting more and more important. Urban climatology in urban planning is a very important measure of adaptation to climate change.

The city of Stuttgart enforces the efforts on urban climatology. In 2011 a European project will start on the urban heat island, considering the heat stress with calculations and measurements and with the development of climate adaptation strategies.

Further on in the city planning of Stuttgart a decision support system will be worked out in the concept of inner development instead of outer development. City quarters have to be developed density, but with a high quality concerning urban climate.

REFERENCES

City of Stuttgart, 2008, Urban Climate 21-Basic materials for urban climate and for planning, DVD

City of Stuttgart, 2008, Rahmenplan Halbhöhenlagen (Hillside Development Outline Plan) Office of Urban Planning and Urban Renewal

City of Stuttgart, 2009, For our environment Protecting the climate, conserving resources, saving energy. Available at: http://www.stuttgart.de/img/mdb/publ/17070/43422.pdf

City of Stuttgart, 2010, Global climate change – adaptation and mitigation: The new challenge facing urban climatology, Authors: Reuter U., Hoffmann U., Kapp R., publication series No. 3/2010; available at: http://www.stadtklima-stuttgart.de

Federal German Building Code (Baugesetzbuch, BauGB), 2004, Federal ministry of transport, building and housing, Germany,

Ministry of Economic Affairs Baden-Württemberg (Ed.), 2004 Authors: Baumueller J., Hoffmann U., Reuter U. Climate Booklet for Urban Development- References for urban planning http://www.staedtebauliche-klimafibel.de/

Nachbarschaftsverband Stuttgart, Stuttgart Regional Federation (Ed.), 1992 Authors: Baumueller J., Hoffmann U., Nagel Th., Reuter U. Climate study for the area of the Stuttgart Regional Federation and bordering areas of the Stuttgart region

Verband Region Stuttgart (2008) Klimaatlas Region Stuttgart. Available at: http://www.stadtklima-stuttgart.de/stadtklima_filestorage/download/klimaatlas/Klimaatlas-Region-Stuttgart-2008.pdf

Sustaining the momentum: what next for urban climatology and urban design?

Brian Webb

Introduction

Interaction between urban climatology and urban design has been elusive despite repeated efforts to bring the two practices together (Hebbert and MacKillop 2011). There is still a general need for urban designers and planners to understand the science of urban climatology and the contribution it can make to livability for residents and the improvement of the urban environment. The science too often remains an exclusive knowledge set, not sufficiently translated into language that can be made use of in the design of cities. The collection of papers presented in this book demonstrates both the collaborative potential and the barriers to successful interaction. The science of urban climatology has been explored, as has the practice of urban design, with case studies that show how the two can be coupled in practice.

A joint purpose

Planning for, and with weather, is now back on the global agenda due to the widespread acknowledgment of the dangers that climate change poses for urban environments and the need to make cities more resilient to changes in weather (Bambrick et al 2011; O'Neill and Ebi 2009; Hamin and Gurran 2009). From Hurricane Katrina, to flooding in Brisbane, to the European heat waves of 2003 and 2006, to the freezing temperatures in the UK in 2009, the need for cities to develop not only the methods, but also the institutional capacity, to adapt to changing weather conditions is now starting to receive increased attention. The impacts of global climate change are necessitating new understandings of cities and by extension their climates and built form. There is a need to not only deal with catastrophic natural events but also to manage the incremental changes in weather that are occurring in cities by reducing the urban heat island effect, managing air pollution and cutting greenhouse gas emissions in urbanised areas. As Gerald Mills discussed, there is a need to develop a more holistic urban climate science that takes into account Architectural and Climatological viewpoints.

The micro-climate is affected by street orientation, width-to-height ratios, building height and spacing, the sky view factor with its implications for sun access by day and loss of energy at night, the architectural detail of street frontages, the heat-reflectiveness (albedo) of building form and materials, the incidence of trees, parks and water-spaces, and patterns of vehicle movement as well as the more variable elements of temperature, precipitation, sunlight/shadow, humidity, wind, and air quality (Givoni 1998; Oke 1976). These urban environments are complex and often difficult to model. Mark McCarthy's paper outlined new ways climate models are attempting to take unique urban characteristics into account in the development of climate models and how these advances in modeling can be used to better inform urban climate projections. In terms of planning practice, Erell and associates argue that understanding local climatic issues is key and that it is necessary for architects and planners to become aware of the language of climatically-informed urban design in order to ensure that context specific climatic concerns can be appropriately integrated into developments.

While many of these critical micro-climatic factors are the very elements that planners deal with on a daily basis, for the most part they are

without awareness of how they affect local climatic outcomes (Bosselmann et al. 1995; Ali-Toudert and Mayer 2006). There has however been a recent push to translate climatic data to a broader audience through knowledge transfer initiatives, such as that outlined by Richard Bassett in Birmingham UK where the city and university worked together to develop the Birmingham Urban Climate Change with Neighbourhood Estimates of Environmental Risk project. At the same time climate change has resulted in an increased awareness of urban climatology as a field of study and a wider knowledge of the need to consider thermal comfort in planning practice, as discussed by van Hove and colleagues in the Netherlands.

Other contributors explored urban climatology and design from a historical perspective, tracking the development of climatic awareness within cities and in some cases noting the slow decline of urban climate considerations in city building as the disciplines of planning and micro-climatology drifted apart. Sue Grimmond's paper comprehensively explored how urban climatology developed in London in response to the varied climatic conditions that are now wide spread throughout metropolitan global cities. Csilla Gal, meanwhile, provided a historical architectural point of view exploring the relationship of the built form in Budapest and local climate considerations while Katja Eßer explored the climatic impact of changing urban layouts in Aachen in the 1800s and concluded by noting the negative effect that development since the 19th century has had on nocturnal cooling and air quality in the city.

Additional papers in this book explored this issue, discussing how contemporary planners may know of the general benefits of street trees in urban environments but not which species to plant for which type of environment, or how far apart and in what arrangement. Potcher and colleagues explored a non-traditional climatic environment; that of desert cities and the impact vegetation has on mitigating heat stress. Similarly with the design and placement of parks, empirical investigation of 'park island' microclimates supplements the conventional planning perspective based on human user requirements as discussed by Hatuka and Saaroni in the development of Jaffa Slope Park. Wind, perhaps the least recognised climatic factor, has become critical for urban heat island management, and for adaptation to the turbulent weather patterns associated with global warming.

Some of the most interesting discussion at the workshop concerned the new availability of wind-field models of air flow at the neighbourhood and even the urban scale. Considerations of wind were highlighted in Rohinton Emmanuel's exploration of how a staggered built form coupled with street trees and orientated towards the prevailing wind offers positive urban warming mitigation impacts for warm humid cities as well as Sascha Henninger's discussion of building arrangements in neighbourhoods in South Korea.

Moving forward

Some efforts have been made to implement climate considerations into urban planning and design. Jeffrey Raven highlighted how climate-resilient urban design is being institutionalized through the use of building rating and municipal indexing systems that take into account how well buildings and developments take climatic considerations into account. Others, such as Jennifer Cox, have developed new methods for understanding the interface between suburban planning regulations and climatic outcomes while Cavan and Kazmierczak explain how climate projections and green space cover models can be used to develop different scenarios so that opportunities can be realized and potential barriers broken down. In these discussions the urban heat island effect is often explored as a concept that urban planners are becoming increasingly aware of.

A well-developed device to link urban climatology to urban planning is the urban climate map. We heard how the practice originated and has spread internationally, especially in hot tropical cities of the Pacific Rim. Ren, Ng and Katzschner outlined how the use of maps enables urban climatologists to disseminate complex data and translate abstract climatic principles into tangible spatial recommendations. Planners and urban designers, in turn, can use the Klimaatlas as a resource upon which to draw when making policy decisions. Ulrich Reuter explored the Stuttgart experience and discussed how the process of developing an urban climate map itself becomes a tool for cross-disciplinary collaboration resulting in communication between the two practices and as a source of synergy.

Yet these experiments remain exceptional. The research communities of climatology and planning remain largely separate, with their own professional networks, conferences and journals. The City Weathers workshop was a welcome effort to engage across disciplines, and deserves to be built on. Already there is follow up, with discussions about the creation of urban climate maps for additional cities and fresh research initiatives.

An interdisciplinary group of researchers, doctoral students, architects, planners and government officials, including some of those in attendance at the workshop, are joining together in Hong Kong for a workshop on Urban Climatology for Tropical and Sub-Tropical Regions sponsored by the Croucher Foundation. Dublin, Ireland meanwhile will host the 8th International Conference on Urban Climate and 10th Symposium on the Urban Environment in August of 2012.

Through additional collaboration urban climatologists and urban planners and designers can better contribute to more liveable and sustainable cities. As the dangers of climate change become more apparent inter-disciplinary knowledge transfer has grown and continues to explore new potentials. Hopefully the foundations that have recently been laid provide an adequate basis for moving forward together in the future.

REFERENCES

Ali-Toudert, F. and Mayer, H. (2006) “Effects of Street Design on Outdoor Thermal Comfort“ Impacts of street design on outdoor thermal comfort. Proc. Fachtagung METTOOLSVI, 14-16.

Bambrick, H., Capon, A., Barnett, G., Beaty, R., and Burton, A. (2011) ”Climate Change and Health in the Urban Environment: Adaptation Opportunities in Australian Cities” Asia-Pacific Journal of Public Health. Supplement to 23 (2), pp. 67S– 79S.

Bosselmann, P., Arens, E., Dunker, K. and Wright, R. (1995) “Urban Form and Climate: Case Study, Toronto” Journal of the American Planning Association, 61 (2), pp. 226-239.

Givoni B (1998) Climate Considerations in Building and Urban Design New York: Van Nostrand Reinhold

Hamin, E., and Gurran, N. (2009) "Urban Form and Climate Change: Balancing Adaptation and Mitigation in the U.S. and Australia” Habitat International 33 (3), pp. 238-245.

Hebbert, M. & MacKillop, F. (2011) “Urban Climatology Applied to Urban Planning - a knowledge circulation failure” [pre-submission manuscript of contribution to International Journal of Urban & Regional Research symposium 'Planning Histories and Practices of Circulating Urban Knowledge', accessible at http://www.sed.manchester.ac.uk/architecture/research/csud/workingpapers/VJmodellingoct2010.pdf

O’Neill, M. and Ebi, K. (2009) “Temperature Extremes and Health: Impacts of Climate Variability and Change in the United States” Journal of Occupational & Environmental Medicine. 51 (1), pp 13-25

Oke TR. (1976) “The distinction between canopy and boundary-layer heat islands” Atmosphere 14: 268–277

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From 1964 - 1971 Study of Meteorology at the University of Karlsruhe and Hamburg. 1971 - 1973 Employee of the State Capital Stuttgart as Urban Climatologist. 1973 - 1978 Scientific Employee at the Institute of Physics of the University of Hohenheim. 1978 - 2008 Director of the Department Urban Climatology in the Office of Environmental Protection of the State Capital Stuttgart. 1979 PhD at the University of Hohenheim. 1981 - 1986 Chairman of the German Meteorological Society (DMG) expert committee "Environmental Meteorology" (FA AKUMET). Since 1982 Lecturer at the University of Stuttgart, Institute of Landscape planning and Ecology. Ecology II: The urban climate. Since Oct. 1993 Honorary Professor. 1984- 1996 Member of the German Enginiering Society (VDI)-committee "Urban climate and air pollution" of the VDI Commission "Reinhaltung der Luft". 1988- 1993 Lecturer at the College of Technic in Stuttgart in the Topic "Environmental protection". October 2009 Retired as Director of Urban Climatology.

Dr Gina Cavan

Dr Gina Cavan is a Research Associate in the Centre for Urban and Regional Ecology, School of Environment and Development, University of Manchester. Gina's research investigates climate change hazards, risk, vulnerability and adaptation in the built and natural environments. She specialises in GIS mapping and modeling of local climate and environments. Her current research focuses on three research projects: EcoCities; GReen and Blue Space adaptation for urban areas and eco towns (GRaBS); and, Climate Change and Urban Vulnerability in Africa (CLUVA).

Dr Ren Chao

Ren Chao is a Post Doctor in School of Architecture at The Chinese University of Hong Kong. She has participated in several important governmental research projects including "Feasibility Study of Urban Climatic Map for Hong Kong", "Eco-Planning for Kaohsiung, Taiwan Using Urban Climatic Map" and "Review of Existing Conditions and an Initial Investigation towards an Urban Climatic Map for Macau". Since 2009 she has been invited to act as researcher in a European Cooperation Project "Future Cities" and to create the first Urban Climatic Map in the Holland. She won the Grand Award in the 11th National Competition of Challenge Cup in 2009.

Ms Jennifer Cox

Currently Ms. Jennifer R. Cox is a Regional Transportation Planner in Strategic Investments Department at Long Island Rail Road (LIRR), were her work focuses on developing five- and twenty-year need strategies for freight movement, transportation oriented development, sustainability, and climate change. From 2001-2008, Ms. Cox was Senior Planner and a Geographic Information Systems Manager at the Regional Plan Association, were her research focused on incorporating climate and energy issues into regional planning and advocacy efforts. Ms Cox's projects combine multiple scales and interdisciplinary approaches to garner local, regional, and national attention needed to address climate and energy policy. Ms. Cox is a Ph.D. Candidate in Earth and Environmental Sciences at City University of New York (CUNY) Graduate Center. Jennifer received a Masters Degree in Geography from CUNY Hunter College and a Bachelors Degree in Geography from SUNY at New Paltz.

Prof Rohinton Emmanuel

Rohinton Emmanuel's work is centred on the sustainability implications of urbanisation and is specifically focused on three inter-related areas: urban climate change and its mitigation/adaptation, energy and thermal comfort implications of urbanisation and sustainability assessment of the built environment. All three of these strands are evident in his teaching and knowledge transfer roles and have been published in over 50 research papers. As an Architect with urban design interests, Rohinton has pioneered the inquiry of urban heat island effect in warm, humid cities, its energy, thermal comfort and quality-of-life consequences and its adaptation/mitigation using urban design and planning strategies for over 15 years. His work in this area also encompasses urban thermal comfort changes, air quality implications of urban growth and the role of urban transport planning in overcoming the negative environmental consequences of urban growth. These efforts are widely published and include An Urban Approach to Climate Sensitive Design: Strategies for the Tropics, (Taylor & Francis, London, 2005). Rohinton is the Secretary (2010-2012) of the International Association for Urban Climate and is a member of the Expert Team on Urban and Building Climatology (ET 4.4) of the World Meteorological Organization (WMO) (2006-2010) as well as the CIB Working Group (W108) on Buildings and Climate Change (2009- onwards).

Ms Katja Eßer

Since summer 2009, I'm working on a doctoral study on the subject of an environmental history of Aachen in the 19th century as a part of the project “City 2020+” at the Human Technology Centre (funded by the Excellence Initiative of the German Federal and State Governments). From 2002 to 2008 I studied history, art history and political sciences at RWTH Aachen University. During this time, I did internships at the Suermondt-Ludwig-Museum / Aachen, at the Dombauverwaltung / Cologne and at the Kulturstiftung der Länder / Berlin and worked as a student assistant at the Departments of History and Art History. After the Magistra Artium's degree in history I contributed to the project “Route Charlemagne_Station Rathaus” as a scientific assistant at the Department of Art History in Aachen.

Ms Csilla V Gal

Csilla Gal received her M.Sc. in architecture and building engineering from Budapest University of Technology and Economics in 2002. Within the confines of the Erasmus Programme she attended the M.Sc in Solar Energy Engineering program at the Dalarna University, Borlänge, Sweden. The outcome of this program was a joint theses with Zsuzsa Szalay, entitled the Energy Conscious Retrofit of Single Family Houses: Comparison of Sweden and Hungary. Before pursuing her Ph.D., Csilla taught at her mother university as an Adjunct Lecturer and obtained a Hungarian architectural license in 2005. She entered the Ph.D. program of the College of Architecture, at IIT, Chicago soon after. As a Ph.D candidate she currently is working on her thesis (Rethinking the urban block in the light of changing climate, A case study of Budapest) under the supervision of Prof. Peter Land AA Dipl., RIBA, M.C.P. Her research area is climate-sensitive urban design with a special focus on Budapest.

Prof Sue Grimmond

Sue Grimmond has been a Professor at King's College London (Chair in Physical Geography) since January 2006. Prior to that she was Assistant, Associate and Full Professor at Indiana University, Bloomington USA. She completed her undergraduate degree at the University of Otago, New Zealand, and graduate degrees at The University of British Columbia (with Tim Oke). She is past President of the International Association of Urban Climate (IAUC) and past Lead Expert for the WMO on Urban and Building Climatology. Sue is on the editorial boards of Journal of Applied Meteorology and Climatology; Agricultural and Forest Meteorology and Advances in Meteorology. In 2006 she was elected Fellow of the American Meteorological Society and awarded Doctor of Science Honoris Causa, from Göteborg University, Sweden. In 2008 she was awarded the Universitatis Lodziensis Amico Medal from

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Dr Tali Hatuka

Dr. Tali Hatuka, an architect and urban designer, is the Head of the Laboratory of contemporary Urban Design. Hatuka works primarily on social, planning and urban issues, focusing on the relationships between urban renewal, conflicts and life in contemporary cities. Research topics concerning urban design include: Housing developments, focusing on analyzing and developing new forms of housing, taking into account physical design, economy and environmental issues as a premise to better, more livable neighborhoods. The political dimensions of urban design and the role of the citizen in modifying altering space. Spatial conflicts, focusing on methods of both intervention and evaluation, tackling socio-spatial problems such as urban segregated neighborhoods, urban poverty, etc. Visioning and utopian thinking as a planning tool and a methodology of thinking on urbanism.

Prof Michael Hebbert

Michael Hebbert has been a Professor of Town Planning at the University of Manchester since 1994, is a member of the Royal Town Planning Institute and an elected member of both the Academy of Urbanism and the Academy of Social Sciences. He read history at Oxford and obtained his doctorate in geography from the University of Reading. He has wide ranging research interests in the fields of town planning history, urban design, and city governance, as well as practical experience in community initiatives and building trusts in London and Manchester, and with design review of the London Crossrail project. His current research into the application of urban climate knowledge in urban design since 1950 is supported by the UK Economic and Social Research Council.

Prof Sascha Henninger

Since March 2009 Prof Sascha Henninger has been a the Professor of the Department of Physical Geography at the Technical University of Kaiserslautern, Germany. From September 2005 until March 2009 Prof Henninger was the Assistant Professor for Physical Geography at the University of Koblenz-Landau, Campus Koblenz, Germany.

Dr. Vladimir Jankovic

Dr. Jankovic's current research centres on the role of British environmental medicine (ca. 1860-1960) in understanding the functioning of the body in relation to seasons, places, and man-made atmospheres. Thematic interests include the examining the descriptive and statistical `Hippocratism' in environmental medicine alongside the more analytical and experimental methodologies used in the medical studies of natural and industrial airs and aerosols. His current research into the application of urban climate knowledge in urban design since 1950 is supported by the UK Economic and Social Research Council.

Prof Lutz Katzchner

Lutz Katzschner is meteorologist and Professor for environmental meteorology at the University Kassel / Germany in the faculty of architecture and urban planning. His main science interest is urban climatic mapping from meso- to mircroscales and their implementation in an urban planning perspective. The indicator is thermal comfort. Hes is chairman of the guideline committee urban climate and planning Verein Deutscher Ingenieure in Germany. He is presently carrying out projects on global warming aspects and their effect in urban climatology in different countries.

Dr Mark McCarthy

Dr Mark McCarthy has been a climate research scientist at the Met Office Hadley Centre since 1999. His research has encompassed a wide range of topics from the role of upper tropospheric water vapour, to the impact of global vegetation on the Indian monsoon. In recent years he has been working with the land surface exchange scheme in the Met Office climate models to explore the interactions between urban-scale climate and the wider regional and global climate.This work sits within the climate impacts team of the Hadley centre and is aimed at exploring potential impacts of climate change on our urban environments, and through wider collaboration within the UK and internationally provide climate science to support the development of adaptation and mitigation advice suitable for the urban environment.

Dr Gerald Mills

I am a physical geographer that has studied urban climatology since 1984. My doctorate at The Ohio State University in 1989 focused on climates in streets and employed a simple (2D) urban canyon model, complemented by observations made in a street. Following this I became interested in extending this approach to three dimensions. I developed a simple cube-based model to look at exchanges within the urban canopy layer (blow roof height). The approach was designed to link studies of the outdoors with those of the indoors using cubes arranged in different arrays. I continue to work on urban climatology and how its knowledge might usefully be employed in aspects of urban design and planning. I am actively involved in the urban climate community and am currently President of the International Association for Urban Climates.

Prof Edward Ng

Prof. Edward Ng is an Architect and a Professor at the Chinese University of Hong Kong (CUHK). He has practised as an architect as well as lectured in various universities around the world. His specialty is in Environmental and Sustainable Design. He is Director of the M.Sc. Sustainable and Environmental Design Programme at CUHK. As an environmental consultant to the Hong Kong SAR Government, he developed the performance based daylight design building regulations and the Air Ventilation Assessment (AVA) Guidelines. He is drafting the Urban Climatic Map for Planning in Hong Kong. Edward is a daylight and solar energy expert advisor to the Chinese Government. As a visiting professor of Xian Jiaotong University, China, he is designing ecological schools, and building sustainable projects in China.

Prof Evyatar Erell

The paper is co-authored by Prof. David Pearlmutter and Prof. Terry Williamson, who are also co-authors of the book Urban Microclimate – Designing the Spaces between Buildings (Earthscan, in press). It will be presented either by David or by Evyatar, both of whom are architects and researchers in the field of energy in the built environment, and are members of Ben Gurion University's Jacob Blaustein Institutes for Desert Research in Israel.

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Jeffrey is an architect and urbanist with over 20 years of US and international expertise in sustainable design, planning and policy. Recent project work includes resilient urban design in India and Vietnam, Masdar carbon-neutral development in Abu Dhabi, green airport design, and adaptive re-use of buildings. He is a technical advisor for the development of a sustainable framework for cities throughout the US called STAR

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Dr Jens Rogée

Jens Rogée was born in Germany in 1975. He graduated from Technische Universitaet Berlin in 2008 holding a diploma in urban and regional planning. During his studies at Technische Universitaet Berlin, urban climatology had aroused his interest and he took several extra-curricular courses in theoretical climatology and attended a meteorological field training in Northern Sweden gathering first experiences in practical climatology. In his diploma thesis he investigated the cooling mechanisms of a street canyon in downtown Berlin. In 2008, after his studies, he joined the research project ‘Urban Agriculture in Casablanca’ as a scientist and PhD-student. The project is embedded within the framework of the German-funded research program “Megacities of Tomorrow - Energy- and climate-efficient structures in urban growth centres”.

Prof Hadas Saaroni

Prof. Hadas Saaroni, a climatologist specializing in urban climatology, applied climatology and climate change. Her studies combine theoretical and applied aspects and focus on the Mediterranean Basin and Israel. Research topics concerning urban climatology and environmental aspects include: Climate change, focusing on indications for aggravation in the summer heat and heat stress conditions. The contribution of moisture to heat stress in a period of global warming, its expected change and implications. Spatial distribution and microscale characteristics of the urban heat island (UHI), as exemplified in Tel-Aviv, Israel. Meteorological and remote sensing techniques for monitoring the UHI and outdoor comfort research issues such as the effect of vegetation, urban parks, water bodies etc. Environmental studies, including NOx pollution potential in metropolitan areas as a function of synoptic and meso-scale conditions, tools for monitoring soot pollution in urban areas and the effect of climate conditions on indoor settled dust.

Dr L.W.A. van Hove

Van Hove graduated as a plant scientist in 1982 at Wageningen University (WU) and obtained his PhD certificate in 1989. From 1983 to 1990 he worked as a junior scientist at the Air Quality group WU, after which he became assistant professor at this group. His main research topic was the interaction between gaseous air pollutants (including carbon dioxide) and the vegetation. At that time, he participated in the National Acidification Research Program. In 2002 he changed of position and started working as a senior scientist at the research institute Alterra (Wageningen UR). He participated in or lead research projects related to soil quality, the nitrogen problem, integral water management, air quality and climate change. Since 2007, he is working as an assistant professor at the Meteorology and Air Quality group (MAQ-WUR) and the Earth Science and Climate change group (ESS-CC-WUR). His current research topic is urban climate which is a new research subject for the Netherlands. He initiated this research and is now project leader of several projects. Also he is supervising PhD students who started working recently on this subject. In addition, he developed and gives courses on climate change (impacts, adaptation and mitigation), air quality and on urban climate.

Dr Brian Webb

Brian Webb is a Research Associate with the Centre for Urban Policy Studies (CUPS) of the School of Environment & Development at the University of Manchester UK, where he completed his PhD in Planning. His topic is intergovernmental spatial policy coordination within federal government systems. He has previously worked with the City of Toronto’s City Planning Department, where he specialised in developing heritage-planning policy, and for the Government of Ontario’s Ministry of Municipal Affairs and Housing, working in both the disaster relief and planning unit and the planning education and training unit. His current interests explore understanding of spatial scale by policy makers.

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