AESOP 2012: Planning to achieve – planning to avoid

# Decisions in time of climate change: The CLUC-model as a tool for spatial planning

Authors: **Michael Richter**, Meike Albers, Sonja Deppisch
Research group "plan B:altic – Climate change and spatial development"
HafenCity University Hamburg
Winterhuder Weg 29
22085 Hamburg – Germany
phone: +49-40-42827-4510
email: michael.richter@hcu-hamburg.de
Keywords: spatial planning, climate change, modelling
Congress track: Vulnerabilities, Risks and Mitigation Planning (12)

**Abstract**

The urban climate effect already poses a challenge in several cities as it leads to the formation of heat islands and therefore to an increase of the morbidity and mortality rate. Due to climatic changes, these effects are expected to increase. However, the consequences of climate change may be reduced by introducing appropriate adaptation measures to cities.

Spatial planning is regarded to play an important role in adapting cities to climate change as it influences the spatial configuration, type and degree of development of buildings and land use, as well as landscapes and green spaces. But especially the uncertainty and the complexity of climate change confront spatial planning with growing challenges and the difficulty to make and justify decisions. Therefore, local experts from Stockholm (Sweden) and Rostock (Germany) lack a basis for decision-making within spatial planning.

The Climate and Land Use Change-model (CLUC-model) can support spatial planning when making decisions with regard to climate change. The model focuses on the interactions between land use and surface temperatures and on the specific air conditions within cities. It allows to project urban temperature differences with regard to different assumptions of (future or planned) land use/land cover and its specific characteristics. Analysing the input parameters of the CLUC-model, spatial planning mainly can influence five parameters: the specific heat of concrete, the average mass of concrete, the building mass per unit of built land, the roughness length and the evaporating fraction at surface. Being aware of the relevance of these five parameters, spatial planning can contribute to the future temperature conditions.

Summarizing, the CLUC-model can support spatial planning in projecting and evaluating adaptation measures by assessing different future land uses and spatial patterns. Therefore, it can serve as a decision-support tool for spatial planning with regard to climate change.

## 1. Introduction

The average annual air temperature in large cities is 1 to 2 °C higher than in the immediate surrounding area – in mega cities differences of more than 10 °C can be determined at certain times (Oke, 1973). In the context of climate change, this could present a growing problem for mankind since rising temperatures may also increase the intensity and frequency of the formation of heat islands. Since over half of the world's population was city-dwellers in 2010 and this tendency is growing (Crossette, 2010), the urban climate effect may impact on an increasing number of people worldwide in the 21st century. More severe consequences can be expected concerning future climate change in metropolitan areas than in their surrounding areas (Früh *et al.*, 2011). If societies are not prepared for such changes, morbidity and the mortality rate will increase due to the consequences of a higher heat load (Souch and Grimmond, 2004), an example of which occurred in France in the summer of 2003 (Filleul *et al.*, 2006). It is assumed that the number of summer days (days with maximum temperature ≥ 25 °C) and hot days (days with maximum temperature ≥ 30 °C) will increase in many regions (Früh *et al.*, 2011), and hence in the areas where people suffer from thermal stress (Souch and Grimmond, 2004).

However, these consequences of climate change may be reduced by introducing appropriate adaptation measures to cities. Spatial planning is regarded to play an important role in adapting cities to climate change as it influences the spatial configuration, type and degree of development of buildings and land use, as well as landscapes and green spaces. Especially the uncertainty and the complexity of climate change confront spatial planning with growing challenges and the difficulty to make and justify decisions.

The article is based on the evaluation of literature and interviews with local experts in the City and Region of Stockholm (Sweden) and the City and Region of Rostock (Germany). In both regions, semi-structured interviews were carried out with local representatives of the departments for spatial planning, landscape planning and environment as well as of the regional planning administration.

As one possible approach to support decision-making within spatial planning, this contribution introduces the Climate and Land Use Change-model (CLUC-model). The model explores the impacts of climate change and land use on surface temperatures as well as the interrelations between them. It is examined in which way the model can support spatial planning when taking decisions and it is planned to evaluate it for Rostock and Stockholm.

First, the focus is on the topic of adaptation to climate change within spatial planning (chapter 2). In chapter 3, the functionality of the CLUC-model is presented. Following this, we discuss how the application of the CLUC-model in planning processes could support spatial planning decisions to influence the future temperature conditions in cities (chapter 4). The contribution concludes with the possibilities as well as the limitations of the model with regard to spatial planning.

## 2. Adaptation to climate change within spatial planning

There is a broad consensus that both mitigation and adaptation to climate change are needed with regard to climate change (e.g. Davoudi *et al.*, 2009; Alberti and Blanco, 2009; Intergovernmental Panel on Climate Change (IPCC), 2007). Within spatial planning, both tasks are considered to be parts of the broader task of climate change planning (Wheeler *et al.*, 2009). Whereas mitigation has long played an important role, adaptation to the impacts of climate change is attracting increasing attention within spatial planning only for some years. In the European Union, the 2001 report by the Intergovernmental Panel on Climate Change (IPCC) is considered providing an important impetus for tackling the topic of adaptation to climate change (Termeer *et al.*, 2009).

The role of spatial planning in adapting to climate change is based on the spatial relevance of both the impacts of climate change and potential adaptation measures (Biesbroek *et al.*, 2009; Fleischhauer and Bornefeld, 2006). For example, a rise in sea level or increasing temperatures could affect cities, necessitating changes in the current land use or influencing decisions on future land use. Since spatial planning influences the spatial configuration, type and degree of development of buildings and land use, as well as landscapes and green spaces, it has an important role to play in adapting to climate change impacts.

However, adapting to climate change confronts spatial planning with growing challenges. These challenges are mainly attributed to the high level of uncertainty, to the dynamic and the long-time horizon of climate change and to the high complexity of cities and regions (Reese, 2011; Hallegatte, 2009).

The uncertainty of climate change is seen as a pivotal challenge for spatial planning (Hall, 2009). Results from empirical studies in Stockholm region (Sweden) and Rostock region (Germany) reveal that local experts assess uncertainty being one of the most important challenges for spatial planning with regard to climate change. Even if planning always had and still has to deal with uncertainty, local experts confirm that climate change seems to exacerbate this problem. In their opinion, climatic changes are more difficult to predict than other future developments. As climate scenarios contain a wide range of potential climatic changes, they are considered to be too vague and imprecise to develop adaptation strategies and measures. Thus, uncertainty is not only about climatic changes, but also about measures and strategies for spatial planning (i.a. Davoudi *et al.*, 2009; Hallegatte, 2009). Otherwise, spatial planners in Stockholm and Rostock are aware that uncertainty cannot be completely eliminated and that they have to find possibilities to integrate uncertain impacts of climate change within spatial planning.

Another challenge can be seen in the dynamic and the long-time horizon of climate change. On the one hand, climate change exceeds the traditional planning horizon that often focuses on the next ten or 15 years (Ritter, 2007). Nevertheless, spatial planning has to consider climatic changes already now as planning decisions influence the spatial structure over a long period of time. Local experts from Stockholm and Rostock emphasise that this is not a completely new challenge as planning always had and has to deal with long-time developments. Within the fields of landscape planning or flood protection, the time horizon is up to 200 years.

On the other hand, climatic changes are characterized by high dynamics (Hallegatte, 2009; Schuchardt and Schirmer, 2005). Local experts in Rostock point out that the dynamic of climatic changes is even more challenging than the long-time horizon. Decisions made today have to be compatible with the current as well as the future climatic conditions: „For an architect, it is not more difficult (nor more expensive) to design a building adapted to the climate of Cordoba than to the climate of Paris. But it may be more difficult (and more expensive) to design a building adapted to both" (Hallegatte, 2009, p. 241).

Furthermore, spatial planning has to deal with the complexity of cities and regions. Interventions such as adaptation measures have manifold impacts that have to be considered while designing adaptation measures and strategies (Aerts *et al.*, 2012). Local experts in Stockholm and Rostock are aware of this complexity and consider climate change as a "very complex and complicated phenomenon".

Despite these challenges, spatial planning has to decide on future developments. This raises the question how adaptation measures and strategies can be justified. Due to the uncertainty and the long-time horizon of climate change, local experts lack a basis for decision-making as they estimate the existing climate scenarios being too weak and imprecise. Taking for granted that climate scenarios will remain uncertain (Hallegatte, 2009), the question arises which methods and processes can serve for decision-making within spatial planning (i.a. Hallegatte 2009; Overbeck et al. 2008).

In the following, we present a model that could support spatial planning in decision-making.

## 3. The CLUC-model

The Climate and Land Use Change-model (CLUC-model) focuses on the interactions between land use and surface temperatures and on the specific air conditions within cities that differ from those in the surrounding countryside. The so-called urban heat island (UHI) effect describes the phenomenon of differing temperature between urban areas and their immediate surrounding rural areas. These differences are primarily generated in urban areas due to large-scale building structures, sealing and emissions from transport and industry.

The CLUC-model explores the impacts of climate and land-use change scenarios on surface temperatures. While causes for temperature differences within urban areas are well understood, it is difficult to map and quantify the spatial configuration of these (Smith *et al.*, 2011).The model allows to project urban temperature differences arising from specific land covers and their specific properties (for instance rate of vegetation cover, impervious surfaces or building height). To do so, the model combines two elements: Climate change scenarios and different types of land use. The climate change scenarios are based on global and regional climate models (downscaled to the city scale). By using different types of land use as input to the model their specific effects on the surface temperature can be compared. There are similar spatial and temporal patterns between air and surface temperatures, although most of the time they do not have exactly the same values (Arnfield, 2003). Surface temperatures vary more (Lowry, 1988) whereas air temperatures are nearly identical across an immediate landscape due to mixing of air (Brown and Gillespie, 1995). The correlation with microscale site characteristics like sky view factor is stronger (Eliasson, 1996) and surface temperatures are less dependent on the unpredictability of wind speed and direction (Whitford *et al.*, 2001). It can serve as a measure of mean radiant temperature and therefore is a significant factor in determining human comfort (Matzarakis *et al.*, 1999).

The surface temperatures are quantified using an energy exchange model previously developed (Whitford *et al.*, 2001) from the urban climate model of Tso *et al.* (1991) and adopted for example for Manchester (Gill, 2006). It is based on following energy balance equation (Figure 1):

$$R = H + LE + G + M$$

R...net radiation flux; balance between incoming and outgoing energy at the surface
H...sensible heat flux due to convection; transfer of heat energy from surface to atmosphere by air movement
LE...latent heat flux due to evaporation; quantity of heat energy released by the surface due to change of state (evaporation)
G...Conductive heat flux into the soil; quantity of heat energy transferred within and between bodies of matter (soil)
M...heat flux to storage in the built environment; quantity of heat energy stored in the built environment

The model solves equations for the terms in the energy balance simultaneous and expresses the balance in terms of the surface and soil temperature ($T_o$ and $T_s$).

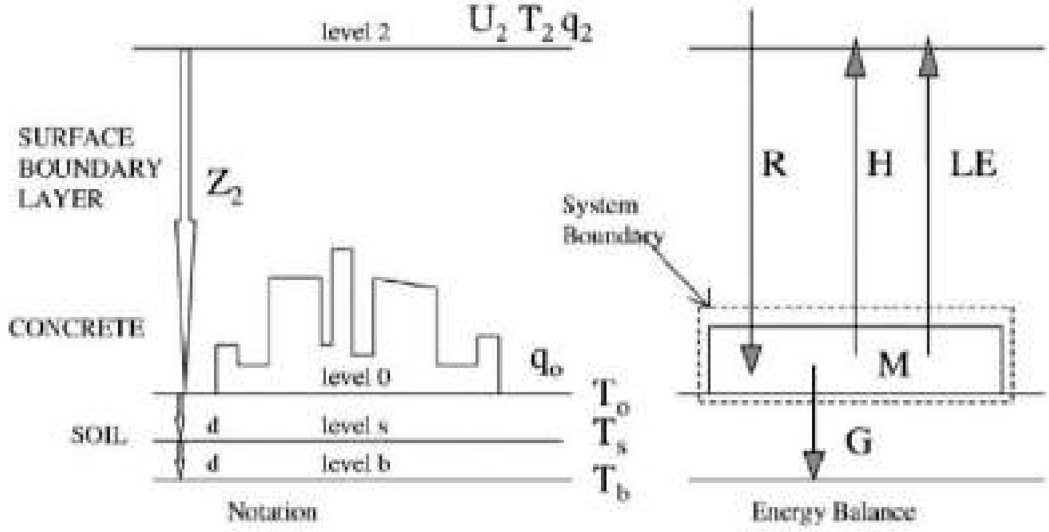


Figure 1. Framework of the energy balance model (Whitford et al. 2001, Tso et al. 1991)

For further explanation of the differential equations see for example Gill (2006) and Tso *et al.* (1991). The process of solving the differential equations during the different time steps is as follows (Gill, 2006):

1. Initial estimate for dawn air and soil temperatures
2. Dawn temperatures as initial conditions for differential equations over the sunny period and simultaneous equations are solved, solutions are taken as sunset air and soil temperatures
3. Sunset temperatures become initial conditions for differential equations over night and simultaneous equations are solved, solutions are taken as midnight air and soil temperatures
4. Midnight temperatures become initial conditions for differential equations over pre-dawn period and simultaneous equations are solved, solutions are taken as the next dawn air and soil temperatures
5. Dawn temperatures from previous day (1.) are compared with new dawn temperatures (4.), if results are unchanged to 3 decimal places no further iterations are carried out, otherwise new dawn temperatures (4.) become initial conditions for 2. and another iteration follows

The surface and soil temperatures are plotted over time and the maximum and minimum temperatures are provided by the model (Gill, 2006). Some input parameters for the model, like air density and specific heat of air, are adopted from previous studies (Table 1). Others are adapted to specific conditions in the case studies of Rostock and Stockholm. Meteorological parameters have to be changed for the assessment of a hot, cloud-free summer day in present and future climate and will vary with different climate scenarios.

Table 1. Input parameters for the energy exchange model (after Gill, 2006).

| **Parameter & notation** | **Unit** |
|---|---|
| Specific heat of air | J/kg/°C |
| Density of air | $kg/m^3$ |
| Thermal conductivity of soil | W/m/°C |
| Specific heat of soil | J/kg/°C |
| Density of soil | $kg/m^3$ |
| Specific heat of concrete | J/kg/°C |
| Latent heat of evaporation | J/kg |
| Average mass of concrete | $kg/m^2$ |
| Building mass/unit of built land | $kg/m^2$ |
| Roughness length | m |
| Height of surface boundary layer (SBL) | m |
| Wind velocity at SBL | m/s |
| Air temperature at SBL | °C |
| Specific humidity at SBL | - |
| Evaporating fraction at surface | - |
| Soil depth | cm |
| Soil temperature at depth 2d | °C |
| Reference temperature | °C |
| Hours of daylight | h |
| Sunrise time | h |
| Sunset time | h |
| Peak insolation | $W/m^2$ |
| Night radiation | $W/m^2$ |

Referring on these input parameters, the CLUC-model allows to project urban temperature differences with regard to different assumptions of (future or planned) land use/land cover and its specific characteristics. By changing the input parameters, it is possible to model the impact of different land use scenarios on surface temperature.

## 4. The CLUC-model as decision-tool for spatial planning

With regard to spatial planning, the crucial question is how the application of the CLUC-model in planning processes could support spatial planning decisions to influence the future surface temperature in cities. To do so, two major questions arise: First, which parameters can be influenced through spatial planning? And second, what can spatial planning do to influence these parameters and therefore the surface temperature within cities?

Looking at the input parameters of the CLUC-model (Tab. 1), spatial planning mainly can influence five parameters:

(1) The parameter ‘specific heat of concrete’ can be changed by using other materials for buildings, streets or places. The higher the specific heat of the materials is, the higher is the capacity to store or carry heat.
(2) Another factor is the ‘average mass of concrete’ that also varies according to the building materials. The temperature is influenced by the specific heat storage mass.
(3) Spatial planning can also influence the ‘building mass per unit of built land’. It mainly depends on the height of a building and the building materials. Higher buildings have a higher building mass and therefore contribute more strongly to increase the temperature.
(4) The ‘roughness length’ describes the surface structure of a city that includes the height of the buildings, the density of an area and the spatial configuration. The lower the buildings and the density, the lower the roughness length and the increase of temperature.
(5) Finally, the temperature is determined by the ‘evaporating fraction at surface’. A lower degree of sealed surface, and therefore a higher evaporative fraction, results in a lower heat effect on the surrounding area.

Being aware of the relevance of these five parameters, spatial planning can contribute to the future temperature conditions. As the urban temperature depends on several other parameters that cannot be influenced by spatial planning (as for example the specific heat of the air or the hours of daylight), there are no generally appropriate measures or strategies to decrease the surface temperature. Therefore, it is very important to take into account the local conditions and their development. By projecting the surface temperature for different land uses, the CLUC-model can support spatial planning in order to make well-founded decisions.

With the help of the CLUC-model, different spatial developments could be compared. Suppose an inner-city area that should be redeveloped: The alternatives are either some flat but extensive buildings or one high building and a small park. By entering the specific data (as well as all the other parameters) into the CLUC-model, the temperature rise for this area can be calculated and the two developments can be compared. Against the background of the uncertainty and the complexity of climate change, the CLUC-model can serve as a decision-support tool for spatial planning.

## 5. Conclusion

Summarizing, the CLUC-model can help to project the effects of changes in land use and building patterns – and therefore of potential adaptation measures – with regard to climate change. The particular added-value of the model is that it integrates future climatic changes as well as potential changes in land use and building patterns. Therefore, it can support spatial planning in several respects:

(1) The model reveals the complex and manifold effects of planning decisions on the future surface temperature.

(2) As the model considers both future land uses and future temperature conditions, it facilitates spatial planning to analyse the interactions between these two components.
(3) By integrating different future temperature conditions, the model provides an opportunity to take into account the whole range of potential climatic changes.
(4) Furthermore, the model allows projecting the effects of different land uses and spatial patterns on the surface temperature. The comparison of different spatial developments can support spatial planners when taking decisions.

Obviously, modelling the effects of planning measures cannot release spatial planning from its duty to define objectives and set priorities with regard to future developments. In addition, the model cannot show differences in air temperatures due to for example inner-urban wind corridors and shading by trees. However, the CLUC-model can support spatial planning in projecting and evaluating adaptation measures by assessing different future land uses and spatial patterns. Therefore, it can serve as a decision-support tool for spatial planning with regard to climate change.

**Acknowledgements**

The authors would like to thank the German Federal Ministry of Research and Education for funding the research work from its Social-Ecological Research Programme (FKZ 01UU0909).

**References**

Aerts, J., Botzen, W., Bowman, M.J., Ward, Philip J. and Dircke, P. (2012), "Introduction: Coastal Cities and Adaptation to Climate Change.", in Aerts, J., Botzen, W., Bowman, M.J., Ward, Philip J. and Dircke, P. (Eds.), *Climate Adaptation and Flood Risk in Coastal Cities.*, Earthscan, London, New York, pp. 1–8.

Alberti, M. and Blanco, H. (2009), "Building capacity to adapt to climate change through planning", in Blanco, H., Alberti, M., Forsyth, A., Krizek, K.J., Rodríguez, D.A., Talen, E. and Ellis, C. (Eds.), *Hot, congested, crowded and diverse: emerging research agendas in planning, Progress in Planning*, pp. 158–169.

Arnfield, A.J. (2003), "Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island", *International Journal of Climatology*, Vol. 23, pp. 1–26.

Biesbroek, R., Swart, R.J. and van der Knaap, W.G.M. (2009), "The mitigation–adaptation dichotomy and the role of spatial planning", *Habitat International*, Vol. 33, pp. 230–237.

Brown, R. and Gillespie, T. (1995), *Microclimate Landscape Design: Creating Thermal Comfort and Energy Efficiency*, John Wiley & Sons, Chichester.

Crossette, B. (2010), *State of the world population 2010*.

Davoudi, S., Crawford, J. and Mehmood, A. (2009a), “Climate change and spatial planning responses”, in Davoudi, S., Crawford, J. and Mehmood, A. (Eds.), *Planning for climate change: strategies for mitigation and adaptation for spatial planners*, London/Sterling VA, pp. 7–19.

Davoudi, S., Crawford, J. and Mehmood, A. (Eds.) (2009b), *Planning for climate change: strategies for mitigation and adaptation for spatial planners,* London/Sterling VA.

Eliasson, I. (1996), “Urban nocturnal temperatures, street geometry and land use”, *Atmospheric Environment*, Vol. 30 No. 3, pp. 379–392.

Filleul, L., Cassadou, S., Médina, S., Fabres, P., Lefranc, A., Eilstein, D., Le Tertre, A., Pascal, L., Chardon, B., Blanchard, M., Declercq, C., Jusot, J.-F., Prouvost, H. and Ledrans, M. (2006), “The Relation Between Temperature, Ozone, and Mortality in Nine French Cities During the Heat Wave of 2003”, *Environmental Health Perspectives*, Vol. 114 No. 9, pp. 1344–1347.

Fleischhauer, M. and Bornefeld, B. (2006), “Klimawandel und Raumplanung: Ansatzpunkte der Raumordnung und Bauleitplanung für den Klimaschutz und die Anpassung an den Klimawandel”, *Raumforschung und Raumordnung*, Vol. 64 No. 6, pp. 161–171.

Früh, B., Becker, P., Deutschländer, T., Hessel, J.-D., Kossmann, M., Mieskes, I., Namyslo, J., Roos, M., Sievers, U., Steigerwald, T., Turau, H. and Wienert, U. (2011), “Estimation of Climate-Change Impacts on the Urban Heat Load Using an Urban Climate Model and Regional Climate Projections”, *Journal of Applied Meteorology and Climatology*, 2011, pp. 167–184.

Gill, S.E. (2006), “Climate change and urban greenspace”, PhD Thesis, Faculty of Humanities, University of Manchester, Manchester, 2006.

Hall, J. (2009), “Integrated assessment to support regional and local decision making”, in Davoudi, S., Crawford, J. and Mehmood, A. (Eds.), *Planning for climate change: strategies for mitigation and adaptation for spatial planners /// Planning for climate change: Strategies for mitigation and adaptation for spatial planners*, Earthscan, London/Sterling VA /// London, pp. 236–249.

Hallegatte, S. (2009), “Strategies to adapt to an uncertain climate change”, *Global Environmental Change*, Vol. 19 No. 2, pp. 240–247.

Heiland, S. and Kowarik, I. (2008), “Anpassungserfordernisse des Naturschutzes und seiner Instrumente an den Klimawandel und dessen Folgewirkungen”, *Informationen zur Raumentwicklung* 6/7.

Intergovernmental Panel on Climate Change (IPCC) (2007), *Climate change 2007: synthesis report*, Paris.

Lowry, W.P. (1988), *Atmospheric Ecology for Designers and Planners*, Van Nostrand Reinhold, New York.

Matzarakis, A., Mayer, H. and Iziomon, M.G. (1999), “Applications of a universal thermal index: physiological equivalent temperature”, *International Journal of Biometeorology*, Vol. 43 No. 2, pp. 76–84.

Oke, T.R. (1973), “City size and the urban heat island”, *Atmospheric Environment*, Vol. 7, pp. 769–779.

Reese, M. (2011), “Synthese: Strukturvoraussetzungen und strategische Kernelemente der umweltrechtlichen Klimaanpassung“, in Reese, M., Möckel, S., Bovet, J. and Köck, W. (Eds.), *Rechtlicher Handlungsbedarf für die Anpassung an die Folgen des Klimawandels*, Erich Schmidt Verlag Berlin, pp. 409–439

Ritter, E.-H. (2007), “Klimawandel eine Herausforderung an die Raumplanung”, *Raumforschung und Raumordnung*, Vol. 65 No. 6, pp. 531–538.

Schuchardt, B. and Schirmer, M. (2005), *Klimawandel und Küste: Die Zukunft der Unterweserregion*, Springer, Berlin.

Smith, C.L., Webb, A., Levermore, G.J., Lindley, S.J. and Beswick, K. (2011), “Fine-scale spatial temperature patterns across a UK conurbation”, *Climatic Change*.

Souch, C. and Grimmond, C. (2004), “Applied climatology: 'heat waves'”, *Progress in Physical Geography*, Vol. 28 No. 4, pp. 599–606.

Termeer, K., Biesbroek, R. and van den Brink Ma, M. (2009), “Institutions for adaptation to climate change. Comparing national adaptation strategies in Europe”, ECPR APSA Panel for Toronto 2009 (September 3-6) on *'Energy Policy and Global Warming: American and European Approaches'*, Toronto.

Tso, C.P., Chan, B.K. and Hashim, M.A. (1991), “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, pp. 413–424.

Wheeler, S.M., Randolph, J. and London, J.B. (2009), “Planning and Climate: an emerging research agenda”, in Blanco, H., Alberti, M., Olshansky, R., Chang, S., Wheeler, S.M., Randolph, J., London, J.B., Hollander, J.B., Pallagst, K.M., Schwarz, T., Popper, F.J., Parnell, S., Pieterse, E. and Watson, V. (Eds.), *Shaken, shrinking, hot, impoverished and informal: emerging research agendas in planning, Progress in Planning*, pp. 195–250.

Whitford, V., Ennos, A.R. and Handley, J. (2001), “"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, pp. 91–103.