🏆 *reviewed paper*

Theoretical and Methodological Framework for the Development of Urban Climatic Planning Recommendation Maps

Sophie Thiel, Florian Reinwald, Astrid Kainz, Claudia Hahn, Daniel Zimmermann, Robert Luger

(DI Sophie Thiel, University of Natural Resources and Life Sciences, Vienna (BOKU Vienna), Peter-Jordan-Straße 65, 1180 Vienna, sophie.thiel@boku.ac.at)

(DI Dr. Florian Reinwald, University of Natural Resources and Life Sciences, Vienna (BOKU Vienna), Peter-Jordan-Straße 65, 1180 Vienna, florian.reinwald@boku.ac.at)

(Astrid Kainz MSc., GeoSphere Austria, Division Climate and Environment, Urban Climate, Hohe Warte 38, 1190 Vienna, Austria, astrid.kainz@geosphere.at)

(Dr. Claudia Hahn, , GeoSphere Austria, Division Climate and Environment, Urban Climate, Hohe Warte 38, 1190 Vienna, Austria, claudia.hahn@geosphere.at)

(DI Daniel Zimmermann, 3:0 Landschaftsarchitektur, Office for climate-sensitive planning, Nestroyplatz 1/1, 1020 Vienna, Austria; dz@3zu0.com)

(DI Robert Luger, 3:0 Landschaftsarchitektur, Office for climate-sensitive planning, Nestroyplatz 1/1, 1020 Vienna, Austria; rl@3zu0.com)

1 ABSTRACT

Urban climatic analyses and planning recommendation maps are becoming increasingly important in the climate-sensitive planning of cities. Urban climatic maps typically include two main components (Ren et al. 2012): an urban climatic analysis map and an urban climatic planning recommendation map. Given the urgent need for action due to climatic changes in urban areas, planning recommendation maps are essential for introducing and locating measures that effectively increase the adaptive capacity of cities, thus increasing the resilience of urban areas and their inhabitants (Baumüller 2015). The first urban climatic maps were produced in Germany in the 1970s and currently they are used worldwide.

The aim of this contribution is to develop a theoretical and methodological framework for the development of urban climatic planning recommendation maps. The main focus is on the review of existing theories and methods that serves as a roadmap for developing these maps. The examples show that these analyses usually consist of four steps or four areas of processing: (i) an urban climatic analysis, (ii) additional in-depth analyses, (iii) the development and location of measures and (iv) the consolidation in a planning information map (Ren et al. 2011).

Within the urban climatic analysis two main approaches are common: pure static GIS (Geographic Information System) derived maps or mainly meteorologically focused maps including the calculation of regional climate simulations (and hybrid forms thereof). Supplementary in-depth analyses are often carried out, such as the intersection with socio-demographic data to identify areas that are particularly vulnerable from a social point of view, or analyses based on specific urban or spatial configurations (Reisinger et al. 2020). In the third step of the process, measures are usually developed at different levels or for different sectors of urban development. As a final step, the results are summarised in planning recommendation maps and the measures are spatially located (Baumüller 2015). Each of these individual steps has been intensively researched in the last few years; the synopsis or bringing together of these numerous research projects and approaches is a gap that this contribution seeks to fill.

The contribution demonstrates available approaches, methods and tools necessary to translate scientific climatic knowledge into urban planning recommendation maps, considering that the analyses for a particular city or municipality are strongly limited in reproducibility to other citys, even in the same country. Based on this, a theoretical and methodological framework for the development of urban climatic planning recommendation maps is elaborated that enables the creation of these.

Keywords: Urban climatic maps, Landscape planning, Urban planning, Climate change adaption, urban climatic planning recommendation maps

2 INTRODUCTION

2.1 Changes in climate signals and impacts on urban development

Urban areas are particularly affected by climate change: the ever-progressing urban development in combination with the increased occurrence of extreme weather events has resulted in a growing number of hot days and warm nights that result in increasing heat stress. In addition, more frequent and intense heavy rain events are expected (IPCC 2021).

Urban climatic maps therefore represent an important link for inter- and transdisciplinary communication and collaboration between urban climatologists, urban planners as well as decision makers and administration employees. They are as well becoming an increasingly important platform to inform planning decisions in the realm of legally binding spatial planning. There are many different approaches to cover and analyse hazards, exposure and vulnerability (see figure 1).

2.2 Hazards, exposure and vulnerability

People, ecosystems and cities and their infrastructures are differently affected or vulnerable to the impacts of climate change. Vulnerability is defined by susceptibility or sensitivity as well as response and adaptation capacity. It is a sub-component and determinant of risk together with the exposure and hazard components. Risks in the context of climate change can "only develop through linkages with exposed and vulnerable societies, cities, infrastructures or ecosystems" (Birkmann et al. 2017, 270). Since adaptive capacity is often difficult to determine and sensitivity is considered by many scientists to be the driving component of vulnerability, in practice, instead of vulnerability analyses, affectedness or climate impact analyses are often carried out (Kemper 2016).

Before the planning recommendation maps are produced, further analyses are often carried out to identify particularly affected areas or vulnerable population groups. In the preparation of planning recommendation maps, various climatic, land use or social data are usually included and combined with local planning or expert knowledge.

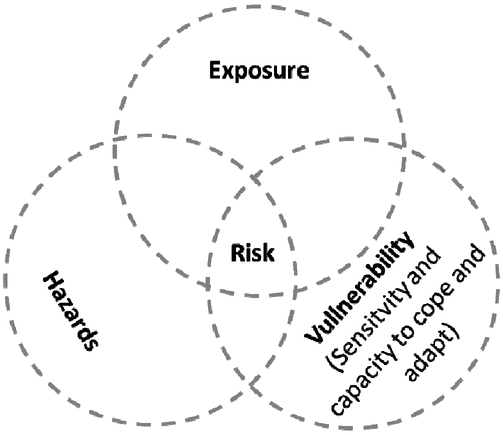

Figure 1: Incorporate hazards, exposure and vulnerability to determine risk as a basis for urban climatic analysis (IPCC 2014, Estoque et al. 2023).

2.3 Urban climate analyses and their use in urban planning

Urban climatic maps are becoming increasingly important in the everyday planning of cities. Urban climatic maps are a climatic information and evaluation instrument to inform planners and policymakers about (changing) urban climatic-environmental conditions and to assist them in urban climate adaptation and mitigation planning (Ren et al. 2012). In order to assist planners and policymakers, the urban climatic knowledge must be translated into a planning language that is actionable in regard to climate change policy (Alcoforado 2006; Alcoforado et al. 2009).

German researchers first developed the concept of urban climatic mapping in the 1970s Stuttgart (Matzarakis 2005) to mitigate air pollution during reduced airflow conditions and to apply climatic knowledge to the planning realm (Ren 2015). In the context of air pollution mitigation programs, urban areas have been identified for planning purposes according to their different climatic functions and characteristics. Based on land use information and its climatic characteristics, the different urban climatic conditions were defined as climatopes - the spatial units of the urban climatic maps (Ren 2015, see chapter 4.1.1.). In the 1990s several cities in Germany (e.g. Stuttgart, Berlin) continued to conduct climatic analyses, resulting in a series of climatic atlases that informed urban planning decisions aiming at improving the exchange of air in these urban areas (ibid). In 1993 the “VDI 3787: Part 1” was published to guide the urban climatic analysis practice in Germany (ibid). This national guideline defines symbols and representations used in UC-Map studies and recommended a rather vague method for developing urban climatic maps with the aim to create a standard for their application (VDI 1997). Since its publication, this guideline has been used as a reference for UC-Mapping and has been adopted and developed by many countries worldwide, with Asian research teams from Japan and China in particular driving the process (Ren 2015; Jégou et al. 2022).

In Austria and Germany, many urban climatic analysis maps are based on this VDI directive, but mostly the maps are tailored to the special needs of a city and thus also differ a lot. Internationally, there are some projects which try to methodically standardise the approach such as the „Urban Climatic Map System" for Dutch spatial planning (Ren et al. 2012) which also mainly follows the German VDI directive or the "Heat Environment Map" from the Tokyo Metropolitan Government (Japan) which indicates 10 types of heat environments (Tokyo Metropolitan Government, 2005).

More and more European cities are commissioning urban climatic analyses or participating in research projects on climate change adaptation in order to generate relevant information to be able to influence their urban development towards more climate resilient structures. However, there is a lack of a strict and applicable methodology for conducting urban climatic maps both for the VDI based and the simulation based climatic analyses as well as for the development of urban climatic planning recommendation maps.

The aim of this contribution is, therefore, to develop a theoretical and methodological framework for the development of urban climatic planning recommendation maps, in order to better guide the conduction of the different steps of urban climate mapping. The main focus is on the review of existing theories and methods that serve as a roadmap for developing these maps that usually consist of four steps or four areas of processing: (i) an urban climatic analysis, (ii) additional in-depth analyses, (iii) the development and location of measures and (iv) the consolidation in a planning recommendation map (Ren et al. 2011).

3 MATERIAL AND METHOD

Since the development of urban climatic analsysis requires a thematic intersection of landscape and urban planning disciplines, meteorology and urban climate modelling and, last but not least, the involvement of planning practice and local decision-makers, an inter- and transdisciplinary approach was chosen.

The contribution is embedded in a "climate proofing framework" (Schindelegger et al. 2022). Climate proofing examines the question of adequate planning responses to climate change-related impacts on planning projects. In addition to the development and implementation of adaptation measures, effective climate change adaptation also requires an analysis and continuous improvement of the (political) decision-making basis, the capacities and competences of planning authorities, and the analysis and planning processes themselves. Following this understanding, "climate proofing" for the (Austrian) spatial planning context comprises three fields of action: (A) the overarching framework conditions and policy objectives, (B) the analysis and strengthening of capacities and competences of planning authorities, and (C) the concrete implementation of climate change adaptation through the integration of relevant steps into planning instruments and planning processes at regional and municipal level (see figure 2).

The contribution focuses on the analysis or improvement of the analysis and planning processes (Part C) by developing a theoretical and methodological concept for the development and implementation of urban climatic analysis aiming at planning recommendation maps as a basis for the adaptation of spatial planning and developments to the challenges of climate change.

The paper is based on an extensive literature review and analysis of the different methods and approaches to urban climatic analysis as well as the necessary steps described in the literature and the instruments and methods used. In addition, numerous practical examples (mainly from Austria, Germany and Switzerland) were analysed and compared to complement the (partly missing) scientific and theoretical approaches.

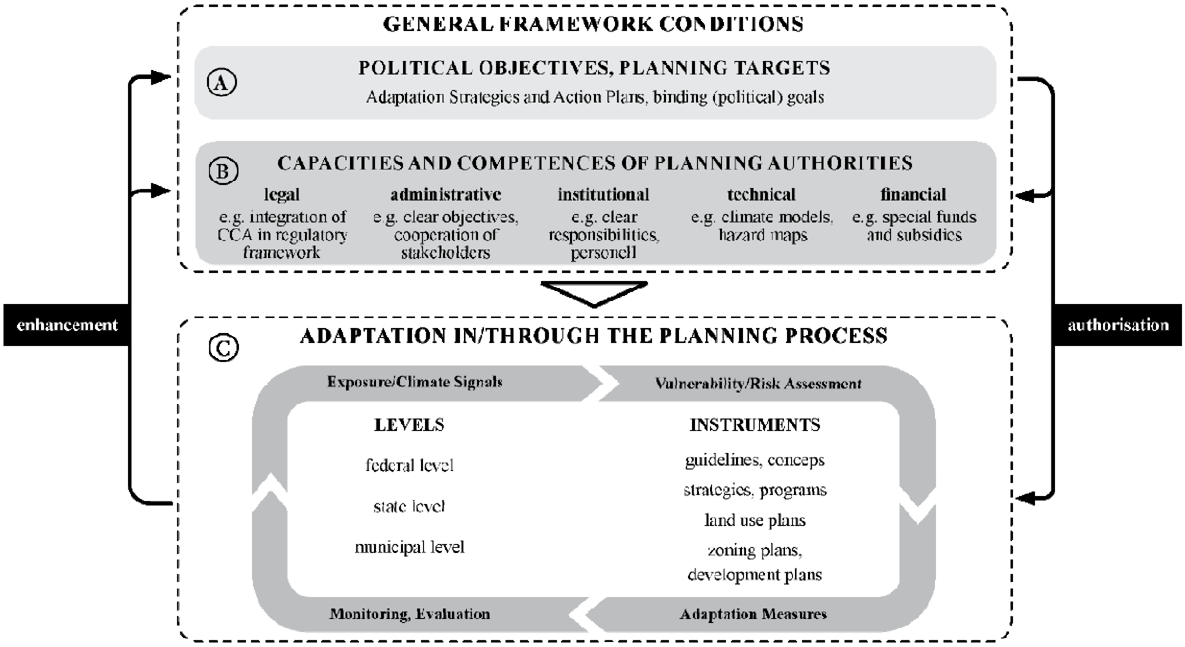

Figure 2: Climate proofing framework © Reinwald, F., Schindelegger, A. & Weichselbaumer, R.; published in: Schindelegger et al. 2021, 2022.

4 RESULTS – METHODS AND STEPS TO DEVELOP URBAN CLIMATIC PLANNING RECOMMENDATION MAPS

Urban climatic maps usually contain two main components (Ren et al. 2012): an urban climatic analysis map and an urban climatic planning recommendation map. Given the urgent need for action due to climatic changes in urban areas, planning recommendation maps are essential for introducing and locating measures that effectively increase the adaptive capacity of cities and thus increase the resilience of urban areas and their inhabitants (Baumüller, 2015). However, scientific disciplines usually develop approaches for their sectors. For urban climatic mapping, this means that the urban climate analysis maps were mostly produced by climatologists and climate impact researchers. The complementary analyses are mostly carried out by planning experts, while the development of measures is dominated by a collaboration between practitioners and researchers, and the planning recommendation maps combine these findings and also incorporate local knowledge (Ren et al., 2011). Thus, not only an interdisciplinary but also a transdisciplinary approach is needed to combine climate and planning science with the knowledge of practitioners and local administrations.

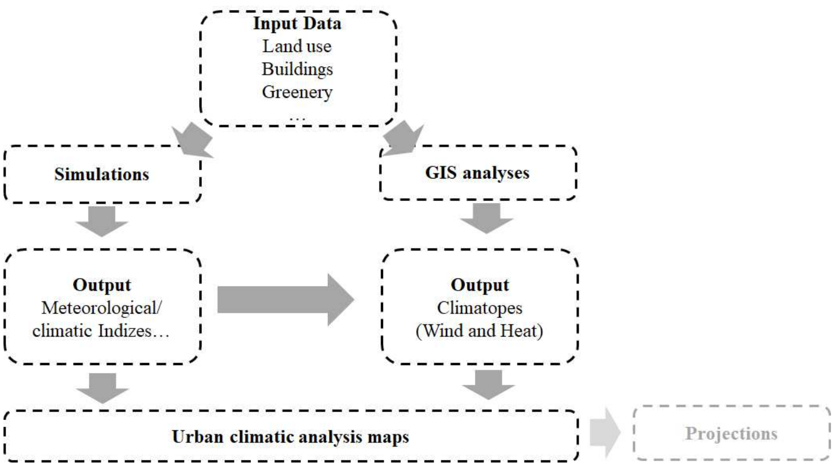

Figure 3: Climate hazard analysis using either Simulations or GIS analyses

4.1 Climate hazard analysis – urban climatic analysis

The urban climatic analysis maps provide a platform for climatic information and evaluation of cities. There are two main climatic aspects examined in urban climatic analysis maps: i) the thermal environment (UHI and heat stress, urban bioclimatic variations) and ii) the wind environment (ventilation zones, local air circulation patterns, existing and potential air paths and the barrier effects by buildings or plants). A third aspect, iii) air pollution, is often additionally included in the analysis (Ren et al. 2011).

Within urban climatic analyses two main approaches are common: pure static GIS (Geographic Information System) derived maps or mainly meteorologically focused maps including the calculation of urban climate simulations (and hybrid forms thereof) (see figure 3). This fundamental difference in the approach affects all further steps of the analysis.

4.1.1 GIS-based analysis and Climatopes

Urban climate analysis based on GIS mapping consists of several input layers typically based on information on land use, topography, vegetation and wind (Ren 2015). Especially in the early days of urban climate map studies the types of climatopes were mainly classified by land use (VDI 1997). Climatopes are the main features of GIS-based analysis maps. Climatopes are non-parcel-specific spatial units that represent areas with similar climatic characteristics which are mainly distinguished by daily thermal variations, the surface structure and vertical roughness, the topographic situation or exposure as well as the type of land use and vegetation cover (Baumüller 2015). Their spatial scales commonly range from several tens to hundreds of metres (Ren et al. 2011). According to the VDI 3787-Part 1 there are nine climatope classes that are named after the dominant land-use type (Water body Climatope, Forest Climatope, Open land Climatope, Urban green space Climatope, Garden city Climatope, Suburban Climatope, City Climatope, Inner City Climatope, Commercial/Industry Climatope, etc.) (VDI 1997). However, climatopes are based on expert knowledge of local topography and climatology and specialized to particular urban areas. Consequently, each city exhibits a unique set of Climatopes meaning that intercity comparisons or generalizations are of limited use (Stewart & Oke 2015). In the first step, Climatopes are derived from the respective georeferenced and land-use data and are classified and allocated. The data basis should be latest digital, geo-referenced data:

- land use data
- topography (e.g. digital elevation model and information on slopes),
- data of building layer (including building height, densityand degree of sealing)
- data of vegetation type and structure
- aereal images with high spatial resolution (VDI 1997).

These data feed various GIS layers – e.g. building volume, ventilation paths, green areas, slopes, etc. – where climatopes can be delineated. This classification of climatopes should then be further improved with information on the distribution of basic climatic parameters (e.g. air temperature, humidity, wind speed and direction, radiation), cold air drainage and thermally induced wind systems, as well as information on human-biometeorological conditions (VDI 1997).

4.1.2 Urban climate simulations

Numerical urban climate models have been developed to analyse physical atmospheric processes within the urban boundary layer (e.g. Sievers et al. 2016; Maronga et al. 2020). They simulate radiation balance, energy exchange and wind flow by taking into account land use and land cover information, urban structures, surface characteristics and vegetation. Different meteorological parameters are calculated to analyse urban climatic conditions and urban heat island (UHI) effect. Combining the results with regional climate models, the models can be further used to provide long-term climate projections on urban scale, considering different greenhouse gas emission scenarios (Früh et al., 2011; Oswald et al., 2020).

In recent years, urban climate models have been extensively used to support urban planning decisions and climate adaptation strategies by providing city-specific climatic information. Covering a broad range of spatial and temporal scales, different types of models are applied to address different problems and to respond to local challenges. While urban climate models are usually applied on city scale and thus, on a level of strategic urban planning, micro-scale models have been designed to simulate the effects of (single) buildings and vegetation on their environment on a microscale, thus considering detailed building geometry and type, surface materials and vegetation properties (e.g. Bruse & Fleer 1998; Lindberg et al. 2008). Due to their higher resolution and enhanced computational requirements, their application is usually limited to district or block level and they are often used within the framework of individual construction projects.

Within the scope of urban climatic analyses, urban climate simulations help to identify regions potentially affected by heat hazards by analysing the spatial distribution of surface or near-surface air temperature or climate indices like the mean annual number of summer days or hot days. As such, they can serve as a basis for generating urban climate analysis maps, covering the thermal component of the analysis. Model results can be further used to derive biometeorological parameters that characterise human thermal comfort like the Perceived Temperature (PT) (Jendritzky 1979), Physiological Equivalent Temperature (PET) (Höppe 1999) or the Universal Thermal Climate Index (UTCI) (Jendritzky 2012). In addition to the thermal component, cold air drainage models are applied to complement the analysis by providing information about important ventilation and cold air pathways (e.g. Sievers, 2005).

4.2 Exposure and vulnerability – in depth social and spatial analysis

People, ecosystems as well as cities and their infrastructures are affected or vulnerable to the impacts of climate change in different ways. For the analysis of exposure and vulnerability, in-depth analyses are carried out according to both social and spatial aspects (see figure 4).

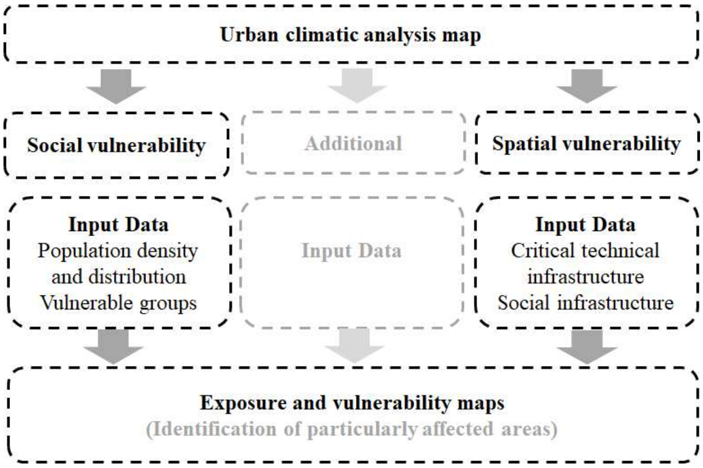

Figure 4: Exposure and vulnerability – in depth social and spatial analysis.

4.2.1 Social vulnerability

The changing temperatures and other climate signals have a strong influence on the human bioclimate. Factors like heat, cold and air humidity strongly influence people's well-being and health. It is therefore important to identify social vulnerability by analysing for example population density or the differing distribution of the most vulnerable groups. The most common demographic indicator groups are elderly residents over 65 years of age and infants and young children. Other socio-economic aspects – such as pre-existing health conditions, ethnicity, gender and income – are rarely considered, even though they influence ones vulnerability to heat and other climate signals as well (APCC 2018; BMSGPK 2021).

4.2.2 Spatial vulnerabillity

For a spatial vulnerability analysis, sensitive facilities such as hospitals or childcare centres can be presented in combination with climatic indicators such as, for example, the average number of hot days. The sensitive infrastructure facilities include facilities that are particularly relevant for the previously mentioned age groups that are especially affected (children, elderly people) as well as other vulnerable groups such as people with care needs (e.g. due to pre-existing health-conditions).

4.3 Vulnerability and adaptive capacity – measures and effects

There are numerous measures that support urban adaptation to climate change. Climate resilient measures can be implemented in existing structures, driven by factors such as heat hotspots or the need for renovations. They can also be incorporated into the development of new climate-adapted buildings and infrastructure. These measures can be categorized into the following groups (Jiricka-Pürrer et al. 2021):

- Strategic measures, such as preserving ventilation pathways and increasing albedo.

- Green infrastructure, including initiatives like tree plantations.
- Blue infrastructure, encompassing approaches like the sponge city principle for roadside trees.
- Technical measures, such as the use of permeable asphalt and water-bound surfaces.

Based on the previous analyses, measures are developed and discussed with local stakeholders. Simulations can then be used to test the impact of the various measures. In this way, their efficiency is assessed and the different locations and their effects are captured (see figure 5).

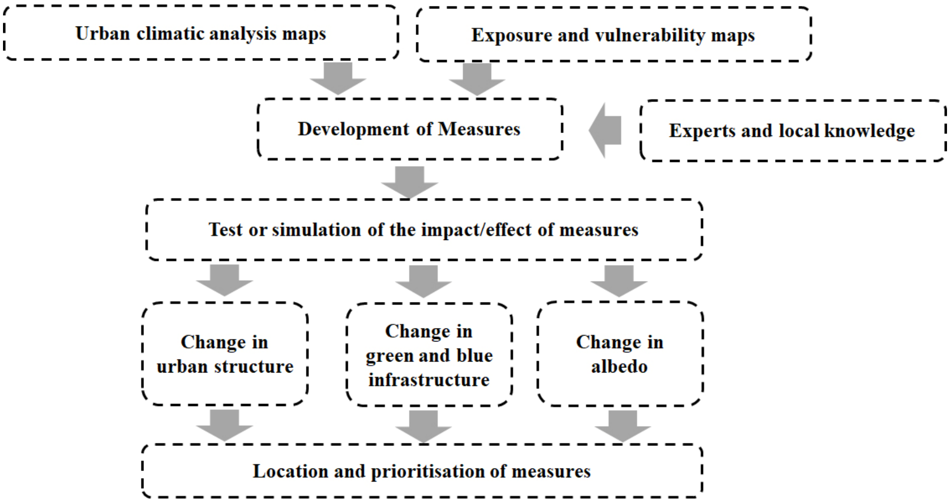

Figure 5: Vulnerability and adaptive capacity – measures and effects

4.3.1 Development of measures

The overarching goal of these measures is to combat heat islands by promoting shaded and green surfaces, reduce the impact of drought through improved local water management and the sponge city principle for roadside trees, and mitigate the consequences of heavy rainfall events through retention spaces like sponge city structures. Changes of the urban structure can also help, for example, to improve ventilation or to make better use of the shading provided by the buildings (MA 22, 2015).

It is crucial for public administrations and businesses to possess climate competence. This includes acquiring the necessary knowledge and skills to implement climate-responsive measures and to prioritise their implementation based on climate fact-based information – a crucial step for which urban climate maps are an aid.

4.3.2 Sensitivity analyses

Not all adaptation measures can be implemented everywhere in a city. Depending on the location or urban typology, only certain measures are suitable or their effectiveness varies.

Urban climate models have been used to evaluate the cooling efficiency of climate adaptation measures by carrying out sensitivity simulations. The potential of different adaptation measures (e.g. implementation of green and blue infrastructure, unsealing or a change in albedo) to reduce thermal heat load can be assessed by the model and the results can be used to support urban planning and climate adaptation strategies (e.g. Oswald et. al., 2020, Zuvela-Aloise et al., 2017).

Depending on the urban context, type of application and considering the model's resolution and planning level, adaptation measures are evaluated on a city scale, as well as on a district or block scale. The measure's efficiency can be expressed in terms of a reduction in local air temperature or heat-related climate indices in comparison to the current situation. Sensitivity analyses have shown that adaptation measures on urban scale are most effective when applied extensively and that a combination of different measures can lead to strong cooling effects (Zuvela-Aloise et al., 2016).

Moreover, sensitivity analyses using urban climate simulations are performed to evaluate impacts of densification and urban sprawl on urban heat load, based on future urbanization scenarios. Depending on the type of model and planning level, the effects of single buildings or entire new development areas on urban temperature can be assessed (e.g. Reinwald et al., 2021).

ISBN 978-3-9504945-2-5. Editors: M. SCHRENK, V. V: POPOVICH, P. ZEILE, P. ELISEI, C.BEYER, J. RYSER, H. R. KAUFMANN – Ljubljana, Slovenia

4.4 Planning recommendations and planning recommendation maps – guidance to reduce the risk

Deriving planning recommendations from the urban climate analysis map is a crucial step to assist planners, policy-makers and decision-makers towards a stronger consideration of climatic criteria. As such, a map with recommendations for planning should contain an integrated assessment of the materials represented in the urban climatic planning recommendations map (Baumüller 2015).

In the final step of creating the planning recommendation maps, the results of the previous analyses are combined and the measures are explicitly spatially located. These maps are an important basis for both strategic planning and zoning and development planning at municipal and regional level.

Planning recommendation maps summarise the analyses obtained and usually combine them with local knowledge on the current situation and possible adaptation options for different urban structures to a varying degree (see figure 6).

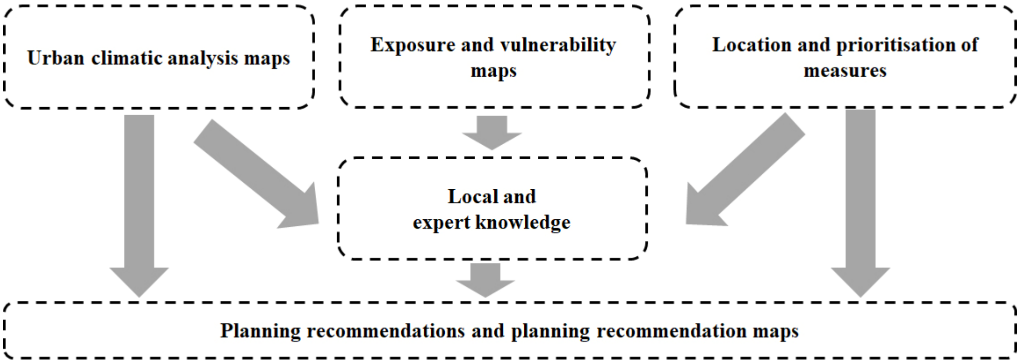

Figure 6: Planning recommendations and planning recommendation maps – guidance to reduce the risk

4.4.1 Combining analysis and local knowledge

Based on the urban climatic analysis maps, an integrated assessment of current climatic spatial characteristics needs to be carried out in order to identify climate-sensitive urban areas that require strategic attention and development. Therefore, at this stage, urban climatologists, planners and policy makers need to work closely together to combine their different perspectives on local knowledge. Different cities have different urban planning systems and climatic challenges, which means that different aspects need to be emphasised when it comes to deriving planning recommendations (Ren et al 2010).

Furthermore, a decision tree can play a crucial role in assisting administrations by providing important guidance for the selection and evaluation of the effectiveness of measures.

4.4.2 Planning recommendation maps

The urban climatic planning recommendation map is an integrated, planning-action-oriented assessment base that can be applied at the regional, city or neighborhood level (Ren et al. 2011). Planning recommendation maps provide general planning advices for sub-areas of the city in order to improve the urban climate in those areas through urban and landscape planning.

Planning recommendation maps usually contain information on two central topics: adaptation measures depending on the thermal load and the urban structure as well as on securing the production of cold air and cold air conduction. A distinction is usually made between "green" areas or areas that have an urban climatic function (cold air production and conduction) and those in which urban overheating occurs – to varying degrees. Recent urban climatic planning recommendation map examples from Germany usually distinguish between three main spatial assessment units:

- Settlement area
- Green and open spaces
- Public roads, paths and squares (e.g. the urban climatic planning recommendation map from Berlin 2015, or Leipzig 2019).

Often, particularly "sensitive" areas are designated where there is a special need for action due to the presence of vulnerable infrastructure or vulnerable populations.

Planning recommendation maps introduce and locate measures that enable urban areas to strengthen their adaptive capacity, respond to a changing climate and thus increase the resilience of cities to adverse climate impacts (VDI 1997).

5 CONCLUSION – THEORETICAL AND METHODOLOGICAL FRAMEWORK FOR THE DEVELOPMENT OF URBAN CLIMATIC PLANNING RECOMMENDATION MAPS

The analysis and descriptions showed that four steps or four areas of processing to develop a sophisticated urban climatic recommendation map are used and necessary (see figure 7):

Step 1: An urban climate hazard analysis is the first step. Two main approaches are visible: GIS-based analysis which result in climatopes which separate a city into different affected areas and urban climate simulations which deliver different climatic indicators to show the different affectedness of urban areas

Step 2: Additional exposure and vulnerability analysis are carried out to analyse in depth the effects on different population groups and their distribution in a city as well as the analysis of exposure and vulnerability regarding infrastructure.

Step 3: Based on the exposure and vulnerability, measures are developed and in many cases their effects are analysed using simulations to verify the adaptive capacities.

Step 4: As a last step, planning recommendation are explicitly spatially located and planning recommendation maps are developed which build a guidance to reduce the risk.

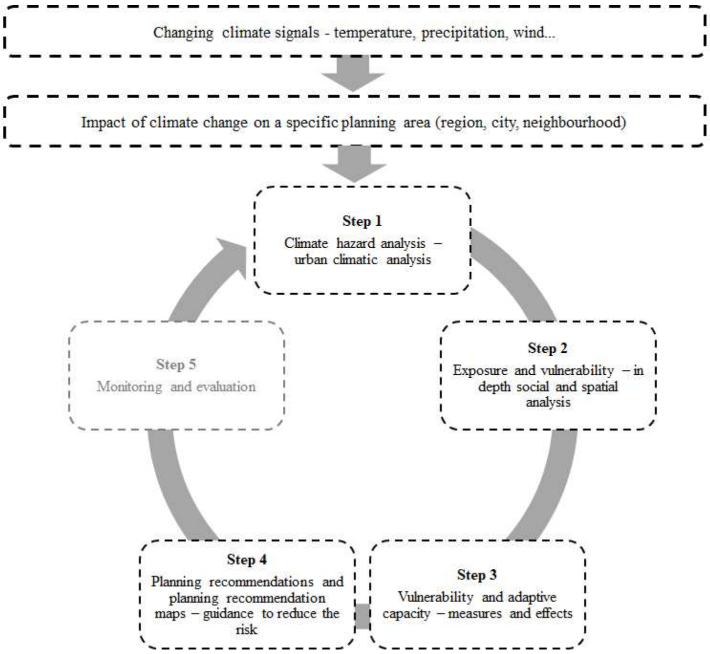

Figure 7: Theoretical and methodological framework for the development of urban climatic planning recommendation maps

The total spectrum of urban climatic analysis maps ranges from purely static GIS (Geographic Information System) derived maps to mainly meteorological maps including urban climate simulations. A thorough analysis that supports subsequent climate-responsive urban planning processes requires the combination of static data and urban climate simulation results, potentially complemented by microclimate simulation results. Therefore, a synopsis of GIS-based and simulation-based analyses is necessary. Alternative approaches to urban climatic maps include evaluation of individual parameters from various data sources and the derivation of conclusions:

- Surface temperature from earth observation data (e.g., Landsat-8) may provide information about overheated areas in a city.
- Vegetation data offers information about cold air production areas.
- In-situ measurements can provide point data of several parameters of interest for a required time range or selected days. For further verification of urban climate analysis maps, these measurements are often used in a complementary way.

ISBN 978-3-9504945-2-5. Editors: M. SCHRENK, V. V: POPOVICH, P. ZEILE, P. ELISEI, C.BEYER, J. RYSER, H. R. KAUFMANN – Ljubljana, Slovenia

- Calculation of sun hours in a 3D city model allows to draw conclusions about thermal comfort.

While each of the above-mentioned alternatives (and others) provide information on individual aspects, the holistic synopsis of urban climatic maps provides a more complete picture and allows to explain the interrelationship and impacts of various parameters.

An in-depth analysis of exposure and vulnerability is only carried out in a few projects. However, these analyses help to identify particularly affected groups and areas. This can also be used to better target or prioritise measures for adaptation and/or mitigation – both critically needed in urban planning to react to urban climatic changes as well as demographic changes.

The preparation of catalogues of measures is a common step in the preparation of planning recomendation maps. Whereas few examples and projects explicitly test the impact of these measures to demonstrate the adaptive capacity. However, this is a particularly important step, as the measures can have different effects depending on the urban fabric and the mesoclimatic conditions.

In the area of urban climatic planning recommendation maps, the research gap is even larger and the practice is far less extensive than in the area of urban climatic analysis maps. Only a few Austrian cities – the situation is comparable internationally – have their own climatic analysis map. The urban climatic planning recommendation maps currently available in Austria do not differentiate according to urban structure, use or function. For example, an industrial area can fall into the same category of climatic stress as an inner-city area – with the same recommendations for adaptation. In the planning reality, however, there are different administrative responsibilities for different areas, different policy and control instruments are required, and the possible measures for climate change adaptation and their effects vary depending on the urban planning situation.

Further research is needed to standardise the internationally diverging procedures for generating urban climatic maps, including urban climatic recommendation maps. Most analyses consider only urban warming and the wind field, changes in other climate signals or consequences (increase in heavy rainfall events, increase in drought, etc.) are mostly not considered, which is especially important for urban climate adaptation planning. Further research is also needed on standardisation for the inclusion of other important climate signals. But the biggest gap is in monitoring and evaluation. There are few cases to support an assessment of objective achievement.

6 ACKNOWLEDGEMENT

The research was conducted as part of the project “GreenAdaptation – Adaptive capacities and resilience in urban and landscape planning”, funded by the Austrian Climate Research Program and conducted within the program “ACRP – 14th Call” (KR21KB0K00001).

7 REFERENCES

Alcoforado M.J.: Planning procedures towards high climatic quality cities: Example referring to Lisbon. Finisterra, 41 (82): 49-64, 2006.

Alcoforado M.J., Andrade H., Lopes A., Vasconcelos J.: Application of climatic guidelines to urban planning – example of Lisbon (Portugal). Landscape and Urban Planning, 90(1-2): 56-65, 2009.

APCC – Austrian Panel on Climate Change: Österreichischer Special Report Gesundheit, Demographie und Klimawandel (ASR18). Wien: Verlag der OAW 2018.

Baumüller J.: A summary of key methodologies. In: The Urban Climatic Map for Sustainable Urban Planning, pp.35-44, London and New York, Routledge, 2015.

BMSGPK - Bundesministerium für Soziales, Gesundheit, Pflege und Konsumentenschutz: Soziale Folgen des Klimawandels in Österreich. Wien, 2021. (Federal Ministry of Social Affairs, Health, Care and Consumer Protection: “Social Consequences of Climate Change in Austria”)

Bruse, M., and Fleer, H. Simulating surface–plant–air interactions inside urban environments with a three dimensional numerical model. Environmental modelling & software, 13(3-4), 373-384, 1998

Früh, B., Becker, P., Deutschländer, T., Hessel, J. D., Kossmann, M., Mieskes, I., ... & Wienert, U.: 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, 50(1), 167-184, 2011

Hidalgo J., Lemonsu A., Masson V.: Between progress and obstacles in urban climate interdisciplinary studies and knowledge transfer to society. New York, 2018. Ann N Y Acad Sci. 2019 Jan;1436(1):5-18, 2019.

Höppe, P.: The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. Int J Biometeorol 43, 71–75. https://doi.org/10.1007/s004840050118, 1999

Jiricka-Pürrer, A.; Reinwald, F.; Weichselbaumer, R.; Juschten, M.: Endbericht zur Studie CLIP-OST Climate Proofing – Ostregion Check der Planungssysteme im Burgenland, in Niederösterreich und in Wien zur besseren Bewältigung der Klimawandelfolgen. PGO – Planungsgemeinschaft Ost, Land Burgenland, Land Niederösterreich, Vienna, 2021.

Jendritzky, G., Sönning, W., & Swantes, H. J.: Ein objektives Bewertungsverfahren zur Beschreibung des thermischen Milieus in der Stadt- und Landschaftsplanung (" Klima-Michel-Modell"). Schroedel, 1979

Jendritzky, G., de Dear, R., Havenith, G. (2012). UTCI—why another thermal index?. International journal of biometeorology, 56, 421-428, 2012

Lindberg, F., Holmer, B., Thorsson, S.: SOLWEIG 1.0–Modelling spatial variations of 3D radiant fluxes and mean radiant temperature in complex urban settings. International journal of biometeorology, 52, 697-713, 2008

MA 22 – Environmental Protection Department: Urban Heat Island Strategy, City of Vienna, Vienna, 2015.

Maronga, B. et al.: Overview of the PALM model system 6.0. Geoscientific Model Development, 13(3), 1335-1372, 2020

Oswald, S. M., Hollosi, B., Žuvela-Aloise, M., See, L., Guggenberger, S., Hafner, W., Prokop, G., Storch, A., Schieder, W.:Using urban climate modelling and improved land use classifications to support climate change adaptation in urban environments: A case study for the city of Klagenfurt, Austria. Urban Climate, 31, 100582, 2020

Reinwald, F., Brandenburg, C., Gabor, A., Hinterkörner, P., Kainz, A., Kraus, F., Ring, Z., Scharf, B., Tötzer, T., Damyanovic, D.: Multi-Level Toolset for Steering Urban Green Infrastructure to Support the Development of Climate-Proofed Cities. Sustainability, 13(21), 12111, 2021

Reisinger A., Mark H., Carolina V., et al.: The Concept of Risk in the IPCC Sixth Assessment Report: A Summary of Cross-Working Group Discussions. Intergovernmental Panel on Climate Change, Geneva, Switzerland. pp15, 2020.

Ren C., Ng E., Katzschner, L.: Urban climatic map studies: A review. International Journal of Climatology. 31. 2213 - 2233. 10.1002/joc.2237, 2011.

Ren C., Spit T., Lenzholzer S., Yim H. L. S., Heusinkveld B., van Hove B., Chen L., Kupski S., Burghardt R., Katzschner, L.: Urban Climate Map System for Dutch spatial planning. International Journal of Applied Earth Observation and Geoinformation, Vol. 18, pp. 207-221. doi:10.1016/j.jag, 2012.

Ren C.: A review of the historical development of urban climatic map study. In: The Urban Climatic Map for Sustainable Urban Planning, pp. 11-34, London and New York, Routledge, 2015.

Sievers, U.: Das Kaltluftabflussmodell KLAM_21: Theoretische Grundlagen, Anwendung und Handhabung des PC-Modells, 2005

Sievers, U.: Das kleinskalige Strömungsmodell MUKLIMO_3. Teil 2: Thermodynamische Erweiterungen, 2016

Stewart, I.D.; Oke, T.R.: Local Climate Zones and Urban Climatic Mapping. In: The Urban Climatic Map for Sustainable Urban Planning, pp.397-401, London and New York, Routledge, 2015.

Tokyo Metropolitan Government: Guidelines for Heat Island Control Measures. Retrieved on March 23, 2022 from https://www.kankyo.metro.tokyo.lg.jp/en/about_us/videos_documents/documents_1.files/heat_island.pdf

VDI-Guideline 3787, Part 1, Environmental Meteorology – Climate and Air Pollution Maps for Cities and Regions. VDI, Beuth Verlag, Berlin, 1997/2015.

Žuvela-Aloise, M., Koch, R., Buchholz, S., Früh, B.:. Modelling the potential of green and blue infrastructure to reduce urban heat load in the city of Vienna. Climatic Change, 135, 425-438., 2016

Žuvela-Aloise, M., Andre, K., Kaltenegger, I., Lettmayer, G., Schwaiger, H., Bird, D. N.: Developing Effective Measures for Reduction of the Urban Heat Island based on Urban Climate Model Simulations and Stakeholder Cooperation. In REAL CORP 2017–PANTA RHEI–A World in Constant Motion. Proceedings of 22nd International Conference on Urban Planning, Regional Development and Information Society (pp. 131-137), 2017