3. Urban climate evaluation for city planning

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Abstract

Over the last 40 years, there has been an increasing amount of world interest on urban climatic map (UCMap) Studies. Up to now, there are over 15 countries around the world processing their own Climatic Maps, developing urban climatic guidelines and implementing mitigation measures for local planning practices. Facing the global issue of climate change, it is also necessary to factor the climatic consolidations holistically and strategically into the planning process.
In the literature, the latest concepts are mentioned. Key methodologies, selected parameters, structure and making procedures, mitigation countermeasures and climatic recommendations of urban climatic map studies ware described. More than 30 relevant studies around the world are cited, and both significant developments and remaining problems are discussed. The review noted that the thermal environment and the air ventilation condition within the urban canopy layer play the most important role in the analytical aspects and climatic-environmental evaluation. It is also noted that possible mitigation measures and planned action can include decreasing anthropogenic heat release, improving air ventilation at pedestrian level, providing more shaded areas, increasing greenery, creating air paths, and controlling building construction. Future research should be focused on the spatial analysis of human thermal comfort in urban outdoor areas and climate change impacts and adaptation. It is also important to share the learned lessons and experiences with planners and policymakers in the rapidly expanding cities of the developing countries and regions.

1. Background

Based on the chronology of UCMap studies in the world, it could be observed that more than 15 countries have conducted their own UCMap studies (Ren et al. 2011). Recently, UCMap is of increasing interest in the world. For example, researchers in China, Chile, Singapore, Macau, France and the Netherlands are starting the relevant projects and studies for pursuing good planning and sustainable development.

Urban climate analyses serve as a suitable means of assessing possible climate impacts. Their results are compiled in so-called climate function maps and mapped nationwide. Overheating areas and areas with ventilation deficits, such as densely populated inner cities or commercial / industrial areas with large parking lots and less vegetation are mapped and located just as favour and the potential regions - meadows, forests or other semi-natural areas - which have a positive effect on the urban climate and mitigating the influence on pollution.

A municipal climate adaptation strategy operates in this context with the protection of the climate-ecological potentials and with the rehabilitation of possible deficit areas. This means that e.g. cold air generation areas and outflows with a high climate ecology value are considered particularly worthy of protection. Climate protection in (city) planning, on the other hand, argues for reduction of greenhouse gases savings should be developed to limit the traffic volume or energy expenditure overall. In this interplay, climate adaptation has a passive, sustaining role. The two issues of climate protection and climate adaptation thus appear in the competing competition for the same process of urban planning. Climate change is to reduce greenhouse gases while adaptation looks for ventilation and heat. Wherever there is the possibility to affect the influence of air, these potentials should be used extensively and as efficiently as possible. Planning and development tailored to local climatic conditions serve as a basic prerequisite for well-conceived solutions ranging from building structures to architectural design (including use of living space, building insulation standard, ventilation options within each residential unit, distribution of window openings, passive solar gains, small wind turbines , Building greenery, blue-green infrastructure, targeted colour choice and building technology) are fine-tuned.

An increasing number of people worldwide live in cities. To accommodate urban growth, it is necessary to intensify density in many inner cities. One of the consequences is that already existing urban heat islands (UHI) intensify. Climate change and the predicted increase in the air temperature add to the problem. This means that two of the most serious environmental issues of the 21st century, population growth and climate change, become evident in redensification projects. This case study deals with designing climate-responsive as well as sustainable and energy-efficient development. The aim is to combine high density and high quality.

In order to provide information for the planning institution for the total urban scale and ultimately generate recommendations for urban planning and development under the conditions described above, the urban climate must be observed and evaluated to. To this end, many cities use urban climate maps (Ng & Ren 2015). They are generated using existing international standards in environmental meteorology (f.e. ISO). These describe how urban climate conditions can be cartographically presented, evaluated and used for planning with the help of reference maps. Moreover, urban climate studies can help to increase open space qualities for the improvement of urban live conditions (Lenzholzer 2016).

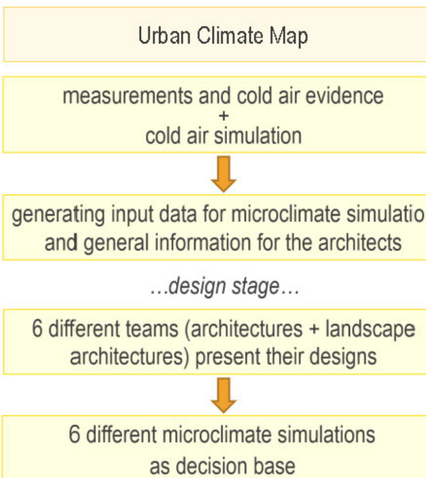

Fig. 1. Example of a flow chart of the procedure urban climatic mapping. for an architectural design competition. Basic line an urban climatic map (Stadt Frankfurt am Main 2016)

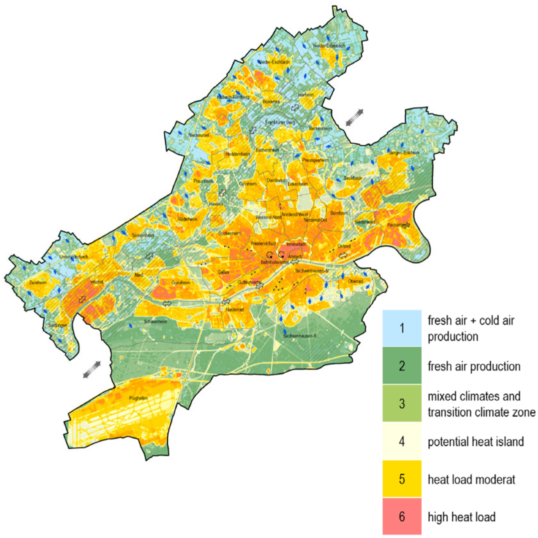

Fig. 2. Urban climatic map of Frankfurt/Main (Stadt Frankfurt am Main 2016)

2. Case Study Frankfurt

The city Frankfurt am Main lies in the centre of Germany in the protected location of the expering northern Oberrheingraben and is the largest city in Hessen and the fifth-largest in Germany. Due to their topographical location on the southern slope of the Taunus and the rivers Main and Nidda, there are still many areas in the city that benefit from the nightly cold air run-off in summer. This outflow is in parts very sensitive and can be blocked by obstacles such as buildings, noise protection or dense tree plantings or at least partially limited in quantity or delayed in time. It is of great importance to maintain the cold air downhill movements as well as the mesoscale ventilation along the rivers.

Other settlements are again surrounded by a cold air system in which several outflows combine locally to form a very powerful outflow stream. In this case too, it is possible to examine whether the urban use and the concomitant reduction of the cold airflow about the overall system are acceptable. The number of possible variables is manageable. The main objective is basically that the current situation should not be significantly worsened. If uses with demand for cold air are within the sphere of influence, structural development should also be avoided.

However, if the analysis reveals that sufficient cold air can escape in a sensitive development or if the outflow is directed in one direction without real needs, then this favourable climatic position can be actively maintained. Structural changes might be possible.

Based on the information retrieved from a mesoscale urban climate map (see Figure 2), it was possible to deduce the conditions for a smaller area of the city. The new development is attached near cold airflow within a climatop (areas of the same climatic characteristics) of importance for the surrounding areas.

The aim in the case of Frankfurt was to create a new inner-city settlement in a climate-sensitive way and to make sure climatic conditions in other parts of the city characterized by higher heat load problems would not deteriorate. Figure 4 shows the planned settlement area. Darker orange to red areas have high heat load conditions with weak ventilation. The area is affected by cold airflow from nearby mountains and can be characterized as a cold air production zone. The urban climate map indicates the thermal conditions using the thermal comfort index. This index called PET is based on the energy balance of a human body and expresses heat or cold stress. This now must be separated to see the effect of ventilation.

After identifying the urban climate functions and interactions, a cold air evaluation was carried out to obtain more detailed information of the fragmented and sensitive cold air situation. The simulation model KLAM_21 was applied to calculate cold airflows in an orographically structured terrain. This is used in urban and regional planning and facility siting. Quantitative statements on the cold air height and the volume flow in two meters above ground in a high spatial resolution were generated (see Figure 2). At the same time, detailed climatic measurements and cold air evidence (tracer gas method, pictures in Figure 3) were carried out in two different spots so that the local conditions could be described quite clearly.

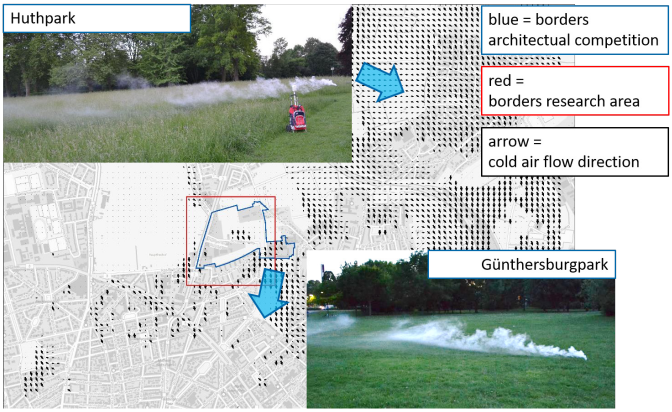

Fig. 3. Cold air calculation, combined with near-surface measurements and cold air evidence by smoke experiment (Katzschner & Kupski 2018)

Figure 3 shows the calculations with the KLAM_21 model and the results of the measurements to ensure these results in the investigation area. The small black vectors show the cold air drain direction in a spatial solution of 40 meters as well as the velocity in three different categories. The large blue arrows represent the direction of the smoke experiment to visualize the atmospheric processes and to validate the calculation at the same time.

The case study was carried out with electronic sensors (Vaisala Weather Transmitter WXT530) and smoke pipes to visualize the nocturnal cold air drainage near the investigation area.
After collecting all this information, a short overview of the most important climatic processes was created and handed over to the planners in order to provide the knowledge needed to prepare the drafts.

The design stage developed next: At the end, six drafts of the new settlement were selected and rated. With regards to the climate criteria, a comparable and transparent calculation of the microclimate was undertaken.

Based on that, an urban climate consideration was carried out with architects and climatologists. Some changes were made, and the reviewed design proposals were simulated. For this task, each draft was calculated by using the three-dimensional microclimate model ENVI-met (pro-version). To predict building design, a numerical simulation was used to understand the climate conditions and the interactions between walls and atmosphere near the ground.

There was a reduction to two relevant parameters in order to not make the decisions more complicated than necessary. These two parameters were the physiological equivalent temperature (PET) value and the wind field two meters above the ground. The focus was on avoiding weak ventilation and allowing wind to penetrate the city pattern. The jury can now easily use the climatic information to come to a decision and choose the winner of the competition (amongst others Figure 4).

3. Results

The result at this stage was a decision, based on many different needs, but also influenced by urban climate information to strengthen the climate-sensitive development of the city. It is obvious that any changes in land use will modify the microclimate. To develop a more satisfactory situation with regards to thermal comfort, it is necessary to manipulate, especially the orientation of buildings, bearing in mind the wind direction and radiation balance.

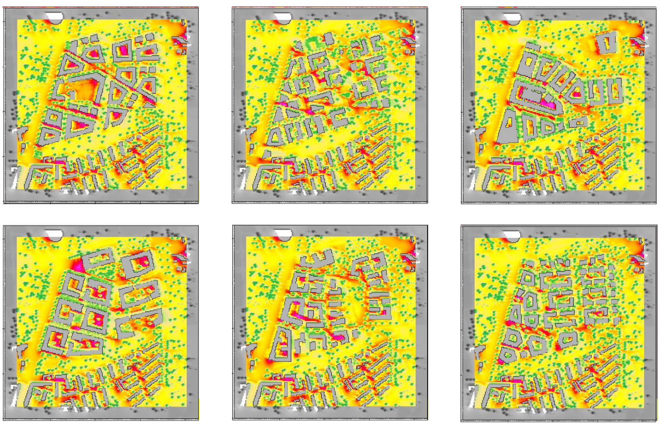

Fig. 4. Finalized studies of the microclimate as decision base (Katzschner & Kupski 2019)

Each architectural team received an objective evaluation of their design based on the microclimate simulation results. It was generally advised to stick to the albedo recommendations on colour sets or natural unsealed surfaces. A precise location of disadvantaged areas and situations with positive effects to the thermal comfort was prepared. In addition to that, the drafts should give an impression of the changes the new area will bring to the urban climate in the surrounding neighbourhoods. To answer this question, the wind field (wind speed and velocity in two-meter height) was simulated. Looking at a heavy traffic road which tangent the development area in the west, e.g. the ventilation is able to reduce the emissions caused by cars. In other areas, the corridors to maintain the city ventilation were checked meticulously. Its mesoscale potential is high; we could, therefore, conclude that one has to prevent the air path from east to south-west direction. This was then incorporated into most proposals. The winning project featured large green areas in the direct neighbourhood which could assist the local ventilation pathways and compensate some of the heat load. Another climate criterion was met by reducing the height of the buildings and planting large trees in order to reduce the heat load in some of the courtyards.

The next steps are already decided: The revised winning draft will be recalculated including the previously prepared climatic information to optimize the simulation base. This calculation can show in much more detail the effects of the new development and is as close to reality as possible.

4. Conclusion

If cities worldwide want to be well prepared for and resilient to climate change and its effects like the rise of air temperature, the increase of heavy precipitation events, the rise of the sea level etc. they need information in the form of the current analysis data to calculate their individual risk level today. After that, each planning or land-use change must be crosschecked to show the local effect so that an adaptation strategy to future requirements can be developed. Planning needs to be aware of urban climate issues. Amelioration can only work if planning is based on a smart platform.

The procedure shows an effective way of proceeding in the process of densification. Urban climate information is needed beforehand, followed by the architecture design proposal, which is again crosschecked with microclimate modelling. This way, redensification in cities can be organized, providing the highest possible thermal comfort. It is also by the current German guidelines VDI 3787 Part 1 and 3787 Part 8 with the title: urban planning and climate change (Verein Deutscher Ingenieure 2015; Verein Deutscher Ingenieure 2017).

This best practice framework should be part of each large inner-city development. The advantage is the objective and transparent approach. So, it is very important to accompany the process with experts from the beginning. Many elementary requirements must be respected in the early process steps like main corridors and building structure. Other issues like local thermal hot-spots or wind discomfort can be solved later.

It is also very important to convince the planners, politicians and decision-makers as well as the population to support the process. They will be rewarded with a liveable city.

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