Land use changes and effects on heat islands in the city

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Abstract. Because of ongoing climate change cities need to take into account also temperature rise issues during projects preparation and in general planning, in order to mitigate heat stress problems. This paper shows the possibilities of applying the Urban Climate model in connection with the evaluation of temperature islands when changing land use-land cover. The example of Masaryk Square in Hodonin shows that small technical solutions can improve the thermal stress islands in urban areas. In the second part of the paper, the results of assessing usability of the model’s application in the form of the Climate-fit.city service using the cost benefit analysis are outlined. In conclusion, the opinions of the representatives of the town of Hodonin for which this service was created are summarized.

1. Introduction
Climate changes are an integral part of human history. As indicated by [1], the temperature at 13 ka BP (kilo annum (thousand years) before present) was even higher than it is today. Just as nature reacts to climate changes, as proven by many paleontological findings for example among bugs [2], people must respond to climate changes as well. These climate changes have started to be recognized in recent decades. Climate changes bring along, among other things, the temperature rise in the whole of Europe [3] and also in other parts of the world. It is also to be expected that the heat waves that are linked to this trend will continue [4].

The increase in average annual temperatures can also be expected in the Czech Republic [5]. Overall climate changes have been addressed in the Czech Republic by developing adaptation strategies to climate changes at state level, and in some municipalities [6]. All of them agree that one of the important elements which can contribute to the deterioration or to improving the condition are land use changes.

Hazards arising from heat waves can lead to increased mortality [7]. In this context, it is the mortality caused by the temperature increase in the environment in which a person lives and the resulting health problems. For example, [8] identified elevated risks in the elderly for temperature-induced cerebrovascular, cardiovascular, and respiratory outcomes as a main issue. As confirmed by several studies, this trend of temperature rise and the formation of UHIs (Urban Heat Island s) is more significant in the urbanization process [9]. Because about 55% of the planet's population lives in urban areas [10] it is necessary to pay particular attention to cities and their population to identify problems and possible measures. In the Czech Republic, the proportion of population living in the
urban areas is even to 70% [11]. This represents a significant part of the population. Historically based development [12] changes land use in urban centres, and also on their outskirts, leading to a number of changes in the climate and microclimate of cities, which must be analysed. The aim must then be to adapt to current natural conditions and also the expected trend so that impacts on the population and its health are minimized.

Climate and microclimate changes in cities are caused not only by external influences but also by internal influences. One major influence is change in land cover and land use. About one-third of the global land surface has already been altered by land use and land cover changes [13]. An integral part of the search and reduction of land cover change issues is the use of materials that reduce carbon footprint. Such materials are discussed, for example in [14, 15].

This article deals mainly with the issue of land cover in terms of the structure of individual elements. It is based, for example, on the description of the relationship between land cover types and climate change that was presented by [16].

A key role in urban decision-making is played by the city administration. Often however the municipality representatives are not able to properly illustrate and evaluate the impact of specific city-planning decisions and strategies on the level of heat stress. Especially, there is a lack of services and tools available for such assessment, based on a decent scientific background that would be user-friendly for city officials and city representatives. For the discussion about the wider context of climate changes, the application of appropriate models which also visualize some of the problems is necessary [17]. Urban planning service Climate-fit city and its application, which is described in this article, is based on the Urban Climate Model [18] owned by VITO. VITO is an independent Flemish research organization in the area of cleantech and sustainable development. This service should assist cities in finding suitable alternatives to changes in landscape in conjunction with spatial planning and urban planning. The aim of the study was to show the possibilities of a variant solution in relation to the creation or reduction of heat islands. To show on a concrete example of Hodonin how important it is to pay attention to these aspects during revitalizations and what direct and indirect benefits the model can bring when used and its outputs incorporated into the project for changing the square.

2. Methodology
The urban planning service focuses on the influence of the urban land use structure (changes of land use and land cover) on the heat stress level and spatial distribution of the heat stress in urban areas. Through modification of the input land use layer, various city-development scenarios can be simulated and the corresponding distributions of the heat stress levels in the area of interest are modelled/re-calculated. This scenario-modelling service is provided in two different spatial scales:

- City level – in 100 m spatial resolution.
- Local level – in 1 m spatial resolution.

Local level results have been chosen for this article. This local level was applied in two pilot areas. Hodonin was chosen for this article, where the area of Masaryk Square was solved. Demonstration of the model application was done according to requests from municipalities. The involvement of pilot cities was important for refining the model application on the pilot area. It was a solution of specific problems in a specific territory with concrete ideas about possible changes in the future. Both model territories are currently in solution and the effects of the changes should be shown in the Urban Climate Model application. Every surface grid cell in Urban Climate Model is assumed to be composed of a mixture of vegetation, bare soil, and urban land cover. The model considers separate energy and water balances for each of the three land cover types. In urban gridcells, the model accounts for anthropogenic heating [18]. In cooperation with VITO, the owner of the Urban Climate Model evaluation of specific problems was prepared. The results were then submitted to the providing city for verification and comment.
2.1 Pilot area
Hodonin is a town in South Moravia, on the border with Slovakia and near the border with Austria. It is a historical city with compact build up area. The Slovakian border is formed by the River Morava. Hodonin has an area of 63.05 km² and a population of over 25,000 residents. This is a town located in the Dolnomoravsky valley, basically a flat area transitioning into the Pannonian plain. Hodonin is historically connected with the extraction of oil. For Hodonin, the model was applied at the local level - in 1m spatial resolution - based on a request from the municipality and with regard to the scale of the projects the municipality prepares.

In Hodonin, Masaryk Square was evaluated, which is located in the very centre of the city and has an area of 1.2 hectares. In the southern part of the square there is a municipal office, in the central part is the Church of St. James and in the northern part there is the Plague Column and parking lot. The square in front of the office is fully paved. There is a fountain in the territory as an element reducing heat stress. The square is surrounded by residential houses with services in the ground floor. Between residential houses and the square there are roads with parking places. The current state of Masaryk Square can be seen in Figure 1.

In total, from 2569 formally registered residents in the Basic Settlement Unit including Masaryk Square and adjacent streets, there are 455 usually resident ones (a place of usual residence is defined as a place where a person usually spends his or her daily rest period regardless of temporary absences due to recreation, visits, business trips, stays at a health care facility, etc. and where it is a member of a particular household), 689 dwellings, 603 occupied dwellings, 267 houses, 236 occupied houses (occupied house is a house with at least one occupied dwelling or a facility for collective accommodation of persons with at least one usually resident person) [19].

3. Results and discussion
For the evaluation it was required to evaluate several scenarios of possible changes in the square. The changes concerned the adjustment of greenery and parking areas. Illustrative screenshot of evaluation of individual scenarios in application of Urban climate model and creation of independent climatological service is shown in the Figure 2.
Figure 2. Clime-fit service – web page.

The first scenario represented a basic variant of the solution, consisting of planting trees with a crown diameter of 3 meters, extension of the parking area and a change in the structure of the current greenery, including removing of current trees. The results are shown in Figure 3, with a red colour indicating a temperature load.

Figure 3. Evaluation of scenario No 1.

The second scenario worked with the same parameters of the parking area and cutting down the current greenery, but counted on trees with a crown diameter of 7 meters. The results can be seen in the Figure 4.

Figure 4. Evaluation of scenario No 2.

The second scenario worked with the same parameters of the parking area and cutting down the current greenery, but counted on trees with a crown diameter of 7 meters. The results can be seen in the Figure 4.

None of the options has brought significant improvements and the project which will increase the amount of parking spaces on one hand will on the other hand also increase the overall heat stress. Trees with a larger crown were rejected due to the character of the square and the views from the windows of the houses. The city representatives therefore discussed what other measures could be applied due to the nature of the territory and utility networks. The modification of the parking space by dividing and utilizing grass tiles appeared to be one of the suitable variants. The output of the mode is shown on Figure 5.
Comparing the individual options, the impacts on the southern part of the square are practically negligible. In the northern part - where the car park will be modified - measures to improve thermal stress are possible.

Hodonín town requested an evaluation of three solution variants for parking areas at Masaryk's Square in Hodonín. This project is under preparation and the final version will have to be approved by the town's council.

3.1 Efficiency and importance of modelling

City-administrations need a scientifically-based justification of anticipated environmental effects in order to enforce the more environmental-friendly urban planning decisions (or city-development scenarios) and to support more sustainable development strategies of their city.

As part of the urban planning, service testing for the local level is 1 m spatial resolution. The problem was tackled in close cooperation with the municipality representatives.

Is necessary identify what costs and benefits will be - if you use Urban Climate Model, [18] aimed at evaluating the impact of implementation of the individual proposals for changing the pilot site (square) to local climatic comfort (heat stress). For the city level of modelling, an interactive scenario modelling tool has been developed, enabling the user to interactively model different scenarios of the city development online and then directly run the modification of the resulting map showing distribution of the heat stress levels in the city.

The service brings to the users the unique possibility to follow the influence of the city structure (spatial distribution of different types of urban land cover and land use) on the level and distribution of the heat stress over the city (or in a smaller area of interest inside the city. The following scheme on Figure 6 identifies the group of costs and benefits that the use of the model can bring. This model - this scheme - was discussed with representatives of the City of Hodonín.
Figure 6. The group of costs and benefits that the use of the model can bring.

4. Conclusion
The application of the model on Masaryk Square showed the necessity of preparing and discussing various possible scenarios. The discussion must include a proposal for appropriate mitigation measures. In particular, the proposal of the third scenario, which respected the requirements for the size of the tree crowns, but also offered a technical solution to alleviate the thermal stress for the inhabitants, was evaluated as positive. Of the 263 houses of the basic residential unit, which will be affected by the overall reconstruction, only the occupants of the houses in the northern part of the square will be directly affected by the change in heat stress. The project for the reconstruction of the square, however, will not bring relief of thermal stress in the southern part of the square, nor in the adjacent streets where no mitigating elements were designed. The whole Urban Climate model as a service built on the scientifically well-proven and reliable modelling method, which is used by the Urban Climate model operated by VITO [18], was assessed as useful. The model represents a very
convincing basis for urban climate data production and modelling. UHIs pose a problem mainly in the rise in the number of hot days and tropical nights [20]. However, city representatives are not interested in running the service independently, but welcome the possibility of external evaluation of a specific problem. The individual parts of the cost benefit analysis were also discussed in cooperation with the City of Hodonín. These benefits - both direct and indirect - have been acknowledged in general, but compared to the expected cost of purchasing the entire climate service, if the climate service would be run as part of the city's GIS environment, they were rated as insufficient. Based on the evaluation and subsequent discussion it is possible to state that the cities perceive the problem of temperature islands and its impact on the health and comfort of the inhabitants.

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