156: Application of micro scale models for bioclimatic assessment – Examples from Freiburg

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Abstract

The place of the old Synagogue is a popular place in the centre of Freiburg, south-west Germany. It is going to be redesigned soon. According to the plans of the city administration, big trees will be removed, new small trees will be planted, and the whole place will be sealed by large plates of natural stone. Both will have strong influence on human thermal bioclimate. Aim of the present study was not only to assess the impact of the redesign on thermal bioclimate, in particular heat stress, but also to show a way of using free models to gain valuable information in short time. The impact of the redesign was estimated using three micro scale models. First, the spatial changes in the sky view factor (SVF) on the place was calculated by the SkyHelios model. The RayMan model was used to show the development in the frequency of thermal stress. Finally the ENVI-met model was applied to calculate the spatial distribution of heat stress on the place. Results show increased frequency of thermal stress, especially heat stress after the redesign. Spatial distribution of heat stress shows strongest impact on heat stress by changes in shading, but also strong impact by changes on surface coverage.

Keywords: RayMan, SkyHelios, ENVI-met, urban design, heat stress

1. Introduction

Urban design strongly influences human thermal bioclimate. According to [1,2], especially shading and ground coverage show great impact. As both shading and ground coverage are influenced by urban design, human thermal bioclimate is also seriously affected. Facing the impact of global climate change especially heat stress should be reduced [3]. According to the "ideal urban climate" a thermal bioclimate with lot of spatial variation, but avoiding extremes" [4] should be the aim of climate correlated urban planning.

2. Data and Methodology

2.1 Area of investigation

For the case study, the "Place of the Old Synagogue" in Freiburg (Fig 1) was selected as area of interest. Freiburg, a medium sized city in southwest Germany, is calling itself a "green city" and has already taken some effort in thermal bioclimate in the past [5]. Furthermore, it is the warmest city in Germany [6,7]. Studies on the impact of climate change predict an increase in heat stress for the city of Freiburg [3]. The Place of the Old Synagogue is a popular place west of the city centre. Being close to the university main buildings and the city theatre, the place has become a popular place for short time recreation and leisure. This place is now going to be redesigned. As the redesign comprises the removal of some of the old trees and the sealing of the lawn by large stone plates, it is matter of a very controversial public debate. Furthermore thermal bioclimate on the place may be strongly affected. This makes it a very interesting subject to show the capabilities of free models in urban bioclimatology.

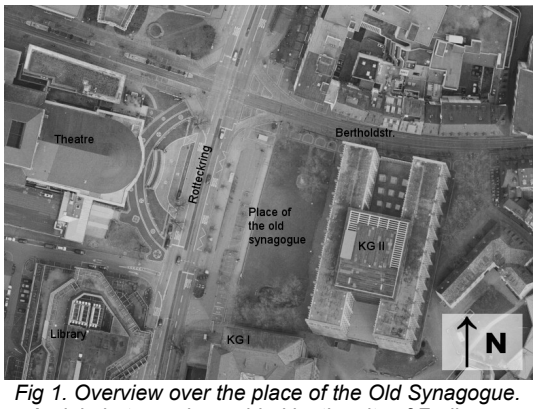

Fig 1. Overview over the place of the Old Synagogue. Aerial photograph provided by the city of Freiburg.

2.2 Data

To run numerical calculations several input data are required. For this study the following data was available as input: An aerial photograph of the current place, the blueprint of the redesigned place, an elevation raster covering the area of interest, and two ESRI®-shapefiles of the surrounding buildings. Also two ENVI-met surface models for the current and the redesigned place were used from a former project [8]. As meteorological input, a ten year period recorded at the urban climate station of the Albert-Ludwigs University Freiburg [9] was used.

2.3 Methodology

For the assessment of the changes in thermal bioclimate caused by the redesign, a combination of three models was used. First the SkyView Factor (SVF) was calculated by the SkyHelios model [10]. SkyHelios was also used to calculate fisheye images, that can be used by the RayMan model [11,12] instead of obstacle files.

However calculating SVF is valuable for a first overview; there are some more parameters driving thermal bioclimate [13]. Thus conclusions are drawn from changes in the human thermal bioclimatic index "Physiologically Equivalent Temperature" (PET) [14,15]. First PET was calculated for a ten year period at seven points on the current and the redesigned place using the RayMan model. Results from those calculations have been classified into nine classes of thermal perception, using an assessment scale [16]. To even more facilitate the results, three combined classes of thermal stress have been summarized [17] (Table 1).

Table 1: Thermal stress classes for humans with an internal heat production of 80 W and a heat transfer resistance of the clothing of 0.9 clo. [17], modified after [16].

PET (°C)	Thermal perception	Grade of physical stress	Combined stress class
< 4	Very cold	Extreme cold stress	Cold
4 - 8	Cold	Strong cold stress	Cold
8 - 13	Cool	Moderate cold stress	Cold
13 - 18	Slightly cool	Slight cold stress	Comfortable
18 - 23	Comfortable	No thermal stress	Comfortable
23 - 29	Slightly warm	Slight heat stress	Comfortable
29 - 35	warm	Moderate heat stress	Hot
35 - 41	Hot	Strong heat stress	Hot
> 41	Very hot	Extreme heat stress	Hot

For the assessment of the spatial distribution of thermal stress on the place calculations with ENVI-met were performed. The model was run twice, for the current and the redesigned place. As thermal stress is mainly a problem during the summer month because people are adapted to cold conditions in winter, a hot and dry period in 2003 was selected. As ENVI-met is a prognostic model, it was not possible to use a seven day record from the urban climate station, but only initial values. To calculate PET, an additional module called "CalcPET" was used.

3. Results

Results of the calculations are structured as follows:
- 3.1: Spatial changes in SVF.
- 3.2: Changes in frequency of heat stress.
- 3.3: Changes in distribution of heat stress.

3.1 Spatial changes in SVF

The SVF on the current and the redesigned place, that were calculated by SkyHelios were compared. It shows, that the central area of the place with high SVF, that is likely to suffer from heat stress, is only little larger after the redesign. At the seven points selected for the calculations with RayMan, the development of SVF is very different for each point (Table 2).

Table 2: Development of SVF at seven points on the place of the Old Synagogue.

Name	SVF before the redesign	SVF after the redesign
Centre of the lawn	0.528	0.537
Southeastern corner (close to KG I)	0.016	0.081
Northeastern corner (close to KG II)	0.380	0.396
Southwestern corner (close to the library)	0.385	0.398
Northwestern corner (in front of the theatre)	0.469	0.446
KG II front door	0.262	0.113
Centre of the place	0.116	0.503

3.2 Changes in frequency of heat stress

The changes in thermal stress due to the redesign is very different at each of the calculation points. As there is only few development looking at the average of all points together (Fig 2), there is strong development found at single points (e.g. Fig 3).

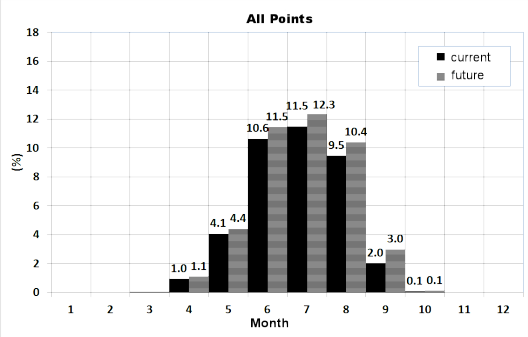

Fig 2. Average development at all points in the frequency of heat stress due to the redesign of the place.

In average at all points frequency of heat stress is increased by up to 1.0 % of all hours in September (7.2 hours in total). In August heat stress occurs more often by 0.9 % of all hours (6.7 hours). Most of the other months show weaker, or less development.
As an example for a single point, point seven is presented here. It is located closest to the centre of the place and it is showing a typical and clear to see development (Fig 3).

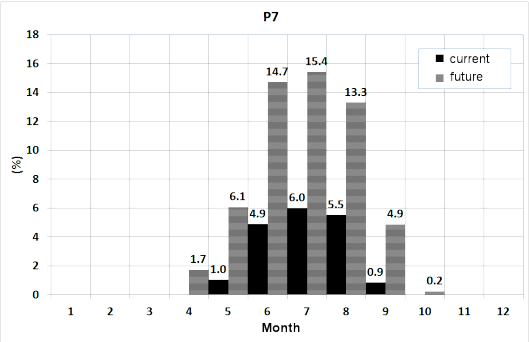

Fig 3. Development in the probability of heat stress at point 7.

After the redesign heat stress occurs at point 7 in April already. During the whole summer the frequency of hours with heat stress is more than doubled. The strongest development can be seen in June, where the frequency is increased by 9.8 %.

3.3 Changes in distribution of heat stress

The results of the ENVI-met calculations for the current (Fig 4) and the redesigned place (Fig 5) for the third day of a hot and dry period were compared.

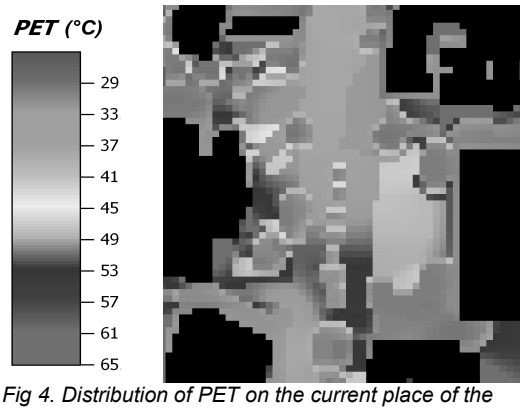

Fig 4. Distribution of PET on the current place of the Old Synagogue on a hot and dry summer day.

In general, a difference of over 10°C (PET) was found between places with and without shading. Most of the trees in the central area of the place will be removed during the redesign. The area with very high PET of around 51°C, thus, will become larger.

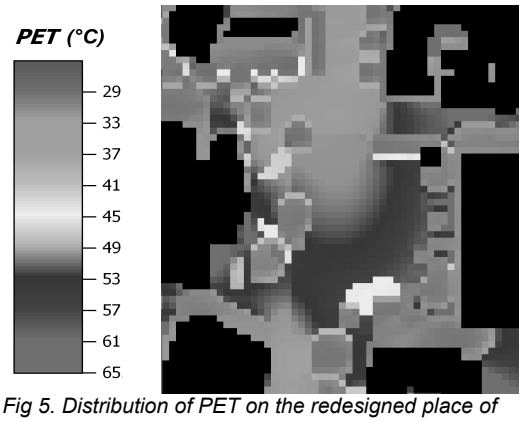

Fig 5. Distribution of PET on the redesigned place of the Old Synagogue on a hot and dry summer day.

Shallow water basins, that will be set up on the redesigned place show slightly reduces PET compared to the lawn on the current place, but only inside the basins. In the central area of the place, that is currently covered with grass and will be replaced with stone plates, show a severe increase in PET of about 6°C.

4. Discussion

Several methods of applied urban climatology have been used for this study. Each of them bears its specific advantages and issues.

SkyHelios: The main advantage in calculating SVF using SkyHelios is, that it is a very fast way to get a first overview over possible changes. However thermal bioclimate depends on many more parameters (e.g. shading), that show stronger influence.

RayMan: The advantages of RayMan are, first, that it is a very fast model, hence requires only little time for computation. This allows to significantly extend the calculated timespan. Furthermore, RayMan is able to use measured meteorological data as input. This allows the usage of a ten year series recorded by the urban climate station Freiburg. Just like most other models, the RayMan model includes simplifications, that may lead to inaccuracy in results. As RayMan is a very common and often used model, severe unknown errors in the model are unlikely. Furthermore RayMan is well validated by several former studies (e.g. [11,12]) that attest RayMan very good accuracy.

Using data recorded by the urban climate station Freiburg, however, causes some uncertainties that has to be considered. First the data had to be altitude corrected. Furthermore the horizontal distance of approximately 800 m between the measuring site and the area of interest may cause uncertainties in parameters that show strong spatial variability, e.g. wind velocity. As this study deals with the comparison of two conditions using the same meteorological input, theses uncertainties should not have much influence on results.

Also the spatial input for the RayMan calculations bear uncertainties that have to be mentioned. The use of fisheye images as spatial input is a very precise method. But as the fisheye images used for the calculations are no photographs, but images calculated by SkyHelios. So the process of their creation, as well as the spatial input, is a potential source of inaccuracy.

ENVI-met: Other inaccuracy has to be respected concerning calculations with ENVI-met. The models high complexity makes it to run very slowly. This limits the timespan, that can be calculated, as well as the model resolution or the size of the area of interest. The imported model areas themselves should not contain severe inaccuracies as they have already been used for another study [8]. However the limitation to the resolution leads to inaccuracy. Due to the low horizontal grids resolution of 3 by 3 m all objects become cuboids. While lager objects are composed by several cuboids, smaller objects

can not be included. Furthermore, the low horizontal resolution leads to inaccuracy in the calculation of radiation and air flow. As these inaccuracies are clear to see in results, they can be easily excluded from the analysis.

5. Conclusions

Even though the SVF is not increased severely, results show that thermal bioclimate is strongly influenced by the redesign. According to the "ideal urban climate" [4] heat stress in summer is to be reduced as far as possible. Calculations with RayMan show, in contrast, that frequency of hours with heat stress is increased after the redesign. From this point of view the redesign leads to minus development. Even more, if the local impact of global climate change is considered, that predicts increased heat stress for Freiburg in general [3]. The spatial distribution of heat stress calculated by ENVI-met shows, that heat stress can be avoided by providing shade. Also the surface conditions shows great influence. Lawn is found to significantly reduce heat stress.

Furthermore results show, that a combination of the three models delivers valuable information, that allow assessment in human thermal bioclimate. All the models used in this study are freely available, and in particular RayMan and SkyHelios are fast models, allowing evaluations in short time.

6. Acknowledgements

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