Modeling of Changes in Human Thermal Bioclimate Resulting from Changes in Urban Design: Example Based on a Popular Place in Freiburg, Southwest Germany

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Abstract The place of the old Synagogue, a popular place in the central area in Freiburg, southwest Germany, is going to be redesigned soon. According to the plans of the city administration, most of the big trees will be removed, some new trees will be planted and the ground coverage will be changed. All of those changes may influence thermal human bioclimate. To analyze changes due to the redesign, a set of three micro scale models has been utilized. The SkyHelios Model was used as a quick overview of the changes in sky view factor (SVF), whereas RayMan was applied to show the changes in the frequency of thermal stress. Finally spatial distribution of heat stress on the place of interest was calculated with ENVI met. Results show that the area with high SVF slightly increases. The frequency of thermal stress, especially heat stress, also increases. The spatial distribution of heat stress shows the highest increases in heat stress due to the changes in ground coverage and shading.

1 Introduction

Urban street design has a strong influence on human thermal bioclimate. Especially shading and ground coverage show great impact (Lin et al. 2010a, b). Thus, if the design of a popular urban place is changed, human thermal bioclimate on the place may be seriously affected. Facing the impact of global climate change especially heat stress should be reduced (Matzarakis and Endler 2010). According to the "ideal urban climate" a thermal bioclimate with "lot of spatial variation, but avoiding extrema" (Mayer 1989) is to be preferred.

Area of investigation: For this study, the place of the old synagogue in Freiburg was selected as an area of interest. This decision is based on several reasons.

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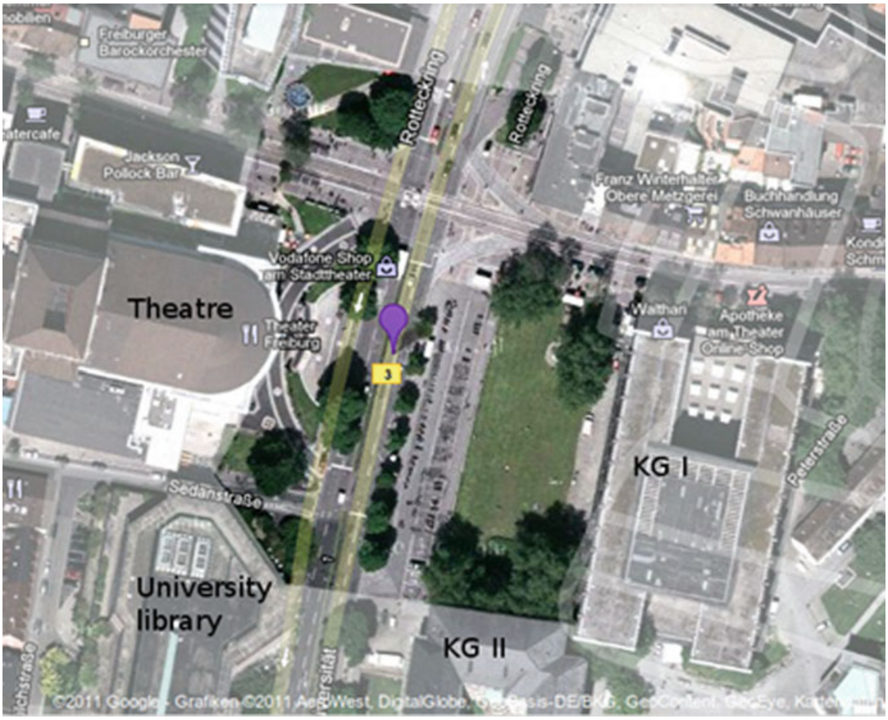

Fig. 1 The current place of the old synagogue (Modified after Google Maps)

Freiburg, a medium sized city in southwest Germany, is calling itself a "green city" and has already taken some effort in human bioclimate in the past (Matzarakis and Mayer 2008). Furthermore it is the warmest city in Germany (Nübler 1979; Rudloff 1993) and studies on climate change predict an increase of heat stress for Freiburg (Matzarakis and Endler 2010). The place of the old synagogue is a popular place in the western part of the inner city. Due to the university and the theater around it, there are lots of people on the place (Fig. 1). This place is now going to be redesigned by the city administration (Fig. 2). As the redesign is a matter of a very controversial public debate, it is a very interesting subject for the present study.

2 Data and Methodology

The changes in thermal bioclimate due to the redesign have been calculated using numerical models. For this study, the three models SkyHelios (Matzarakis and Matuschek 2011), RayMan (Matzarakis et al. 2007; Matzarakis and Rutz 2010) and ENVI-met (Bruse 1999) have been applied. Each model has been used to calculate

Fig. 2 The blueprint of the place of the old synagogue after the redesign (Modified after city administration of Freiburg)

two situations, one for the current place and one for the planned one. Afterwards the results have been compared to show and quantify the changes.

2.1 Data

To allow numerical calculations there are some input data required. For this study an aerial photograph of the current place, the blueprint of the redesigned place (Fig. 2), an elevation raster covering the area of interest, as well as ESRI® shapefiles

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 (Modified after Matzarakis and Mayer (1996))

PET	Thermal perception	Grade of physical stress	Combined 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

of the surrounding buildings have been used. Also two ENVI-met surface models for the current and the redesigned place were used from a former project (Röckle et al. 2010). The 10 year period dataset of the urban climate station of the Albert-Ludwigs University Freiburg (Matzarakis and Mayer 2008) was used to provide the required meteorological input.

2.2 Methodology

For a first overview over the changes, the SVF was calculated by the SkyHelios model. As it is very time consuming to create RayMan obstacle files manually in the RayMan Editor, SkyHelios was also used to calculate fisheye images, that can be used in RayMan instead of obstacle files (RayMan buildings and vegetation files).

Although calculating SVF is good for a first overview, there are many more parameters influencing thermal bioclimate (Mayer and Höppe 1987). Thus conclusions are drawn from changes in physiologically equivalent temperature (PET) (Höppe 1999; Matzarakis et al. 1999). First PET was calculated for a 10 year period at seven Points on the current and the redesigned place using RayMan. Results from those calculations have been classified into nine classes of thermal perception, using the assessment table from Matzarakis and Mayer (1996). To even more facilitate the results, the three classes of cold stress, the three classes for comfortable conditions, as well as the three classes of heat stress have been merged into a cold, a comfortable, and a hot thermal stress class (Table 1).

To analyze the spatial distribution of thermal stress over the place calculations with ENVI-met for a hot and dry 7 day period in 2003 have been performed for the current and the redesigned place. This period was selected because thermal stress is mainly a problem during the summer months as people are more adapted to cold conditions in winter. Therefore an additional module called “CalcPET” was used, as the ENVI-met version 3.1BETA4 can’t calculate PET itself. As ENVI-met is a prognostic model, it was not possible to use a 7 day record from the urban climate station, but only initial conditions.

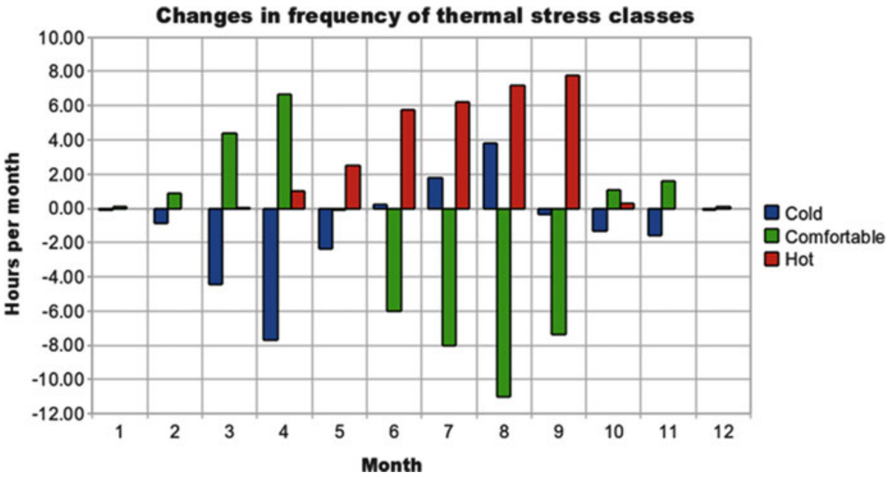

Fig. 3 Changes in the frequency of thermal stress classes at all points due to the redesign of the place of the old synagogue

3 Results

Results of the calculations are summarized as following:

- Changes in distribution of SVF calculated with SkyHelios,
- Changes in long term frequency of thermal stress calculated by RayMan,
- Changes in distribution of heat stress calculated by ENVI-met.

Changes in SVF calculated with SkyHelios: Comparing the SVF on the current and the redesigned place calculated by SkyHelios, it can be seen, that the central area of the place with high SVF, the area with high energy balance, that is likely to suffer thermal stress, is only little larger after the redesign.

Changes in long term frequency of thermal stress calculated by RayMan: The calculations with RayMan show a strong decrease of cold stress in spring and fall, with a maximum of nearly 8 h/month in April (Fig. 3). In summer, an increase in colder conditions with a maximum of nearly 4 h/month in August is calculated (Fig. 3). During the winter months cold stress is little decreased by less than 1 h/month. Looking at the class of thermal comfort (Fig. 3) there is a certain increase in spring and fall. During the summer months, the frequency of thermally comfortable conditions is calculated to be severely decreased by up to 12 h/month in August. There can be nearly no strong changes seen for the winter months. A much more interesting development is shown by the classes of heat stress (Fig. 3), as it only shows an increase. Especially in the summer months the frequency of heat stress is calculated to be severely increased by up to 8 h/month in September.

Changes in distribution of heat stress calculated by ENVI-met: Comparing the ENVI-met results for the current and the redesigned place on the third day, a difference of over 10°C (PET) between places with and without shading can be seen. Because of the trees in the central area of the place that will be removed during the redesign, the area with very high PET of around 51°C will become larger. The new water basins on the redesigned place show slightly reduced PET compared to the lawn on the current place, but only inside the basins. A severe increase in PET of about 6°C is shown in the area in front of the KG II that is currently covered with grass and will be covered with stone plates after the redesign.

4 Conclusions

Even though the SVF does not increase significantly, results show that thermal bioclimate is strongly influenced by the redesign. According to the "ideal urban climate" (Mayer 1989) the reduction in the frequency of cold stress and the increase in the frequency of thermally comfortable conditions in spring and fall is to be seen as an advantage. The strong decrease in frequency of thermally comfortable conditions and the severe increase in frequency of heat stress in summer is, in contrast, a big disadvantage. Both developments are caused by the larger area without shading on the redesigned place, as well as by the change in ground coverage. This also can be seen in the results of the spatial analysis.

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References

Bruse M (1999) Die Auswirkungen kleinskaliger Umweltgestaltung auf das Mikroklima. Entwicklung des prognostischen numerischen Modells ENVI-met zur Simulation der Wind-, Temperature-, und Feuchtverteilung in städtischen Strukturen. Dissertation, University of Bochum, Germany

Höppe PR (1999) The physiological equivalent temperature – a universal index for the bioclimatological assessment of the thermal environment. Int J Biometeorol 43:71–75

Lin TP, Matzarakis A, Hwand RL (2010a) Shading effect on long-term outdoor thermal comfort. Build Environ 45:213–221. doi:10.1016/j.buildenv.2009.06.002

Lin TP, Matzarakis A, Hwang RL, Huang YC (2010b) Effect of pavements albedo on long-term outdoor thermal comfort. In: Matzarakis A, Mayer H, Chmielewski FM (eds) Proceedings of the 7th conference on biometeorology, Freiburg, Germany, 12–14 April 2010. Berichte des Meteorologischen Institutes der Universität Freiburg, vol 20. Meteorological Institute, Albert-Ludwigs-University of Freiburg, pp 498–504

Matzarakis A, Endler C (2010) Climate change and thermal bioclimate in cities: impacts and options for adaptation in Freiburg, Germany. Int J Biometeorol 54:479–483. doi:10.1007/s00484-009-0296-2

Matzarakis A, Matuschek O (2011) Sky view factor as a parameter in applied climatology – rapid estimation by the SkyHelios model. Meteorol Z 20:39–45

Matzarakis A, Mayer H (1996) Another kind of environmental stress: thermal stress. WHO Newsl 18:7–10

Matzarakis A, Mayer H (2008) Importance of urban meteorological stations – the example of Freiburg, Germany. Ber Meteorol Inst Univ Freiburg 17:119–128

Matzarakis A, Mayer H, Izimon M (1999) Application of a universal thermal index: physiological equivalent temperature. Int J Biometeor 43:76–84. doi:10.1007/s004840050119

Matzarakis A, Rutz F (2010) Application of the RayMan model in urban environments. In: Ninth symposium on the urban environment of the American Meteorological Society, 1–6 Aug 2010, Keystone, CO

Matzarakis A, Rutz F, Mayer H (2007) Modelling radiation fluxes in simple and complex environments – application of the RayMan model. Int J Biometeorol 51:323–334

Mayer H (1989) Workshop “Ideales Stadtklima” am 26. Oktober 1988 in München. DMG Mitteilungen 3:52–54, in German (http://www.geographie.uni-freiburg.de/publikationen/fgh-index)

Mayer H, Höppe P (1987) Thermal comfort of man in different urban environments. Theor Appl Climatol 38:43–49. doi:10.1007/BF00866252

Nübler W (1979) Konfiguration und Genese der Wärmeinsel der Stadt Freiburg, Freiburger. Geographische Hefte, 16 (in German)

Röckle R, Hermsdörfer K, Richter CJ (2010) Mikroklimatische Untersuchung Platz der Alten Synagoge im Zuge der Stadtbahnplanung mit Umgestaltung Kronenstrasse, Werthmannstrasse, Rotteckring und Friedrichring. iMA Richter & Röckle GmbH & Co. KG, 09-12-05-FR II (in German)

Rudloff H (1993) Beiträge zum Klima Freiburgs. Lingg Druck (in German), Freiburg