Dependence of urban climate on urban morphology

Andreas Matzarakis, Helmut Mayer

Meteorological Institute, Albert-Ludwigs-University of Freiburg, Germany

Abstract

Sealing factor, sky view factor or aspect ratio of street canyons or urban structures can be used to explain influences on phenomena of urban climate. Based on near-surface air temperature (T_a) data and statistical parameters being calculated from measured T_a values, single and multiple regression analyses were carried out to determine the influence of the sealing factor and sky view factor on T_a characteristics. T_a data measured in the temporary urban climate network within the research project URBAN CLIMATE IN BAVARIA (STADTKLIMA BAYERN) in Munich (south Germany) represent the basis. The results of this re-analysis show that the highest correlation can be reached with the sealing factor for the annual amount of total heat and mean annual T_a for the single regression. In the multiple regressions, the highest regression coefficients are found for the annual number of warm days, total heat and mean annual T_a.

1. Introduction

Many parameters play a significant role in the formation of urban climate, urban heat island (UHI) and urban heat archipelago (UHA), if the intra-urban thermal conditions are analysed. The impact of SVF is particularly important with respect to nocturnal cooling rates, where long-wave radiation is trapped by warm surfaces as opposed to being released to the cold sky hemisphere (Matzarakis and Mayer, 2008). Such a decrease in long-wave radiation loss is directly related to SVF and considered to be a major component of the UHI phenomenon (Oke et al., 1991).

2. Methods

Within the scope of the urban climate research project URBAN CLIMATE IN BAVARIA (STDTKLIMA BAYERN), representative conditions for a horizontal circle with a radius of 100 m around each of the 18 temporary climate stations (1981-1985) in Munich (south Germany) were determined (Fig. 1, Table 1). All climate stations were of a similar type. Based on existing data sets for near-surface air temperature T_a, i.e. near the bottom of the urban canopy layer (UCL), the aim of the present study is to improve the existing knowledge on the impact of the selected urban morphological parameters sky view factor (SVF) and seal factor F_v on the intra-urban thermal conditions. Working hypotheses, objectives, applied investigation design and results of the research project STADTKLIMA BAYERN are explained in detail in the literature (e.g. Baumgartner et al., 1985; Bründl et al., 1986; Mayer, 1986, 1987, 1988)

The following statistical values were available (Bründl et al., 1986):

- mean annual air temperature (MIT) of T_a,
- absolute 30 minute maximum (MAX) and minimum (MIN) of T_a per year,
- mean annual amount of tropical days (TT), i.e. days with a daily maximum air temperature $T_{a,max} \geq 30$ °C,

- mean annual of summer days (ST), i.e. days with a daily maximum air temperature $T_{a,max} \geq 25$ °C,
- mean annual of warm days (wT), i.e. days with a daily mean air temperature $T_{a,mit} >$ 20 °C,

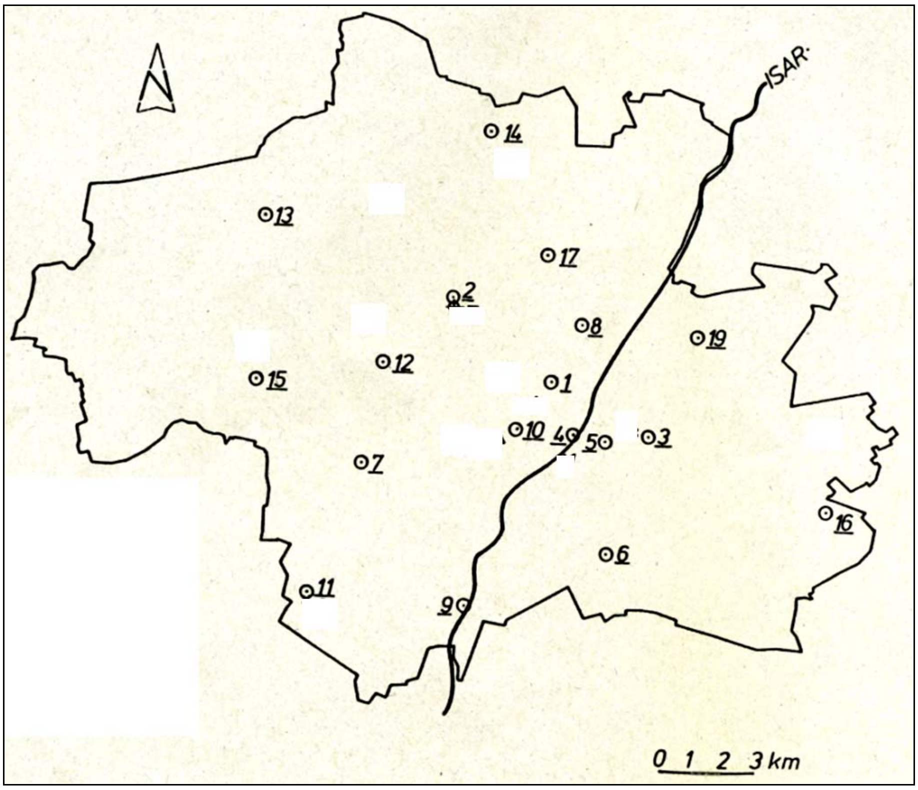

Fig. 1: Screen level urban climate network in Munich (south Germany) from 1981-1985 within the scope of the urban climate research project STADTKLIMA BAYERN (according to Bründl et al., 1986, modified)

- mean annual of heating days (HT), i.e. days with a daily mean air temperature $T_{a,mit} <$ 12 °C,
- mean annual of frost days (FT), i.e. days with a daily minimum air temperature $T_{a,min}$ < 0 °C,
- mean annual of ice days (ET), i.e. days with a daily maximum air temperature $T_{a,max}$ < 0 °C,
- mean annual of cold days (kT), i.e. days with a daily mean air temperature $T_{a,mit} <$ - 10 °C,

- mean annual total of heat (WS), i.e. $\sum_{i=1}^{i=N} T_{a,mit,i}$ with N: of days per year and the limitation for daily mean T_a values: $T_{a,mit,i} > 0\,°C$,
- mean annual total of cold (KS), i.e. $\sum_{i=1}^{i=N} T_{a,mit,i}$ with N: of days per year and the limitation for daily mean T_a values: $T_{a,mit,i} < 0\,°C$.

In the statistical regression analyses, both mean annual T_a values and mean annual thermal characteristics calculated from T_a were the depending variables (Y), while F_v and SVF, respectively, represented the independent variable (X). The regression analyses were carried out in form of a linear regression and in and the independent urban morphological values (seal factor Fv and sky view factor SVF) based on the annual mean values of air temperature Ta in form of equation 1 and 2.

$$Y = a_0 + a_1 * F_v \quad (1)$$

$$Y = b_0 + b_1 * SVF \quad (2)$$

and in form of a multiple regression

$$Y = c_0 + c_1 * F_v + c_2 * SVF \quad (3)$$

Table 1: Sealing factors (F_v) and sky view factors (SVF), mean values of air temperature T_a (MIT), total of heat (WS) and cold (KS), absolute maximum (MAX) of T_a and absolute minimum (MIN) of T_a, mean annual numbers (n/a) of tropical days (TT), summer days (ST), warm days (wT), heating days (HT), frost days (FT), ice days (ET) and cold days (kT) at the stations in the temporary urban climate network in the UCL in Munich (S Germany) within the scope of the STADTKLIMA BAYERN project, averaging period: 1982-1984 (Bründl et al., 1986; Mayer, 1987; Matzarakis, 2001)

station	F_v	SVF	MIT	WS	KS	MAX	MIN	TT	ST	wT	HT	FT	ET	kT
			°C	°C	°C	°C	°C	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1	0.95	0.247	9.3	3572.9	-150.5	38.2	-13.4	8	38	36	219	81	29	1
3	0.75	0.382	8.3	3312.1	-192.6	36.8	-15.8	4	32	26	235	113	32	2
4	0.20	0.150	8.4	3260.0	-172.6	34.6	-14.2	2	20	17	217	97	30	1
5	0.80	0.410	8.9	3447.3	-161.5	37.5	-14.3	7	40	33	225	99	34	1
6	0.30	0.627	8.0	3152.0	-215.9	36.6	-14.8	5	32	21	237	91	29	1
7	0.60	0.614	8.7	3375.1	-192.6	37.8	-13.4	7	40	29	229	107	30	1
8	0.75	0.336	8.8	3420.4	-188.7	36.5	-15.8	4	29	28	227	95	34	2
9	0.05	0.438	7.4	2958.7	-224.2	36.2	-15.2	4	25	13	250	131	31	1
10	0.90	0.326	9.6	3643.2	-137.0	35.9	-13.4	7	42	37	218	80	24	0
11	0.20	0.385	7.9	3117.4	-219.7	37.9	-15.0	5	32	21	240	122	33	2
12	0.80	0.610	8.7	3422.6	-192.5	37.1	-15.1	5	36	27	227	109	32	2
13	0.45	0.649	7.7	3081.7	-251.9	36.2	-17.8	3	33	20	246	127	37	4
14	0.60	0.507	8.2	3224.4	-213.4	37.8	-15.0	7	38	24	236	114	32	2
15	0.75	0.329	8.6	3349.0	-187.1	37.1	-14.8	5	33	28	230	103	30	1
16	0.55	0.766	8.1	3193.2	-227.4	36.2	-19.5	6	36	20	238	122	31	2
17	0.30	0.677	8.6	3373.4	-203.6	37.2	-16.3	7	37	29	229	105	35	2
19	0.70	0.410	8.5	3339.7	-218.4	38.3	-17.8	7	40	28	230	107	34	3

3. Results

The statistical calculations can be interpreted as a re-analysis of urban climate data measured and recorded approximately 20 years ago.

The results for mean thermal characteristics (Table 1) reveal an intra-urban variability, which depends on station-specific morphological parameters. They are exemplarily indicated by simple fish-eye graphics.

The results for the multiple regression analyses are compiled in Table 2. They show:

- As expected, the correlation coefficients for the multiple regressions are higher than the correlation coefficients for linear regressions.
- The correlation coefficient of the multiple regression for the mean annual number of tropical days exceeds the 0.5 threshold.

Table 2: Regression coefficients a_0, a_1, b_0 and b_1 of the statistical analysis as well as correlation coefficients r, basis: statistical thermal values for 18 stations in the temporary urban climate network in the UCL in Munich (S Germany) within the scope of the STADTKLIMA BAYERN project, averaging period: 1982-1984, F_v: sealing factor, SVF: sky view factor, T_a: air temperature (ac-cording to Bründl et al., 1986; Mayer, 1987; Matzarakis, 2001)

	independent variable F_v			**independent variable SVF**		
	a_0	**a_1**	**r**	**b_0**	**b_1**	**r**
mean annual air temperature T_a (°C)	7.5	1.6	0.780	9.0	-1.2	-0.371
mean annual total of heat (°C)	3008.0	529.6	0.818	3467.5	-344.0	-0.332
mean annual total of cold (°C)	-233.2	63.7	0.581	-146.7	-108.9	-0.622
absolute T_a-maxima (°C)	36.2	1.2	0.352	36.6	0.7	0.122
absolute T_a-minima (°C)	-16.0	1.0	0.167	-12.9	-5.3	-0.539
mean annual amount of tropical days	3.7	3.1	0.488	4.7	1.7	0.171
mean annual amount of summer days	26.6	13.6	0.640	29.1	11.3	0.331
mean annual amount of warm days	14.4	20.0	0.835	29.4	-8.1	-0.211
mean annual amount of heating days	242.1	-19.0	-0.555	218.3	28.3	0.518
mean annual amount of frost days	122.3	-28.7	-0.528	87.5	40.0	0.460
mean annual amount of ice days	33.0	-2.4	-0.220	29.0	5.6	0.322
mean annual amount of cold days	1.9	-0.4	-0.109	0.6	2.2	0.401

The results of the linear regression analyses for F_v and SVF are contained in Table 3. The grey colour indicates a correlation coefficient r higher than 0.5. The results in Table 3 can be summarised as follows:

- The strongest correlation exists between F_v and the mean annual number of warm days followed by (i) the correlation between F_v and the mean annual total heat and (ii) the correlation between F_v and mean annual air temperature T_a.
- A trend exists that the statistical values of T_a have a higher correlation with F_v than with SVF. SVF mainly influences the radiation balance and the turbulent transport within the UCL. These effects seem to be lower than for other meteorological parameters in the formation of UHI and UHA, respectively.

- There are no correlations with $r > 0.5$, neither with F_v nor with SVF, for the statistical values of absolute T_a-maxima and the mean annual numbers of tropical, ice and cold days.
- As for the linear regressions, the correlation coefficients of the multiple regressions for the absolute T_a-maxima as well as the mean annual number of ice and cold days do not exceed the 0.5 threshold.
- The mean annual number of warm days and the mean annual total of heat show the strongest multiple correlation with F_v and SVF, followed by the mean annual air temperature T_a and the mean annual number of summer.

The correlation coefficients r for the linear regressions point out that the correlation between T_a and F_v is stronger than for T_a and SVF.

Table 3: Regression coefficients c_0, c_1 and c_2 from the multiple regression and the multiple correlation coefficient r; basis: statistical thermal values for 18 stations in the temporary urban climate network in the UCL in Munich (S Germany) within the scope of the STADTKLIMA BAYERN project, aver-aging period: 1982-1984, F_v: sealing factor, SVF: sky view factor, T_a: air temperature (Bründl et al., 1986; Mayer, 1987; Matzarakis, 2001)

	c_0	c_1	c_2	r
mean annual air temperature T_a (°C)	7.9	1.5	-0.7	0.811
mean annual total of heat (°C)	3107.7	507.0	-187.8	0.837
mean annual total of cold (°C)	-184.0	52.5	-92.7	0.780
absolute T_a-maxima (°C)	35.6	1.4	1.1	0.402
absolute T_a-minima (°C)	-13.2	0.4	-5.2	0.543
mean annual amount of tropical days	2.3	3.4	2.8	0.558
mean annual amount of summer days	18.0	15.6	16.1	0.790
mean annual of warm days	15.4	19.7	-2.0	0.837
mean annual amount of heating days	229.8	-16.1	23.3	0.696
mean annual amount of frost days	105.2	-24.8	32.4	0.642
mean annual amount of ice days	30.3	-1.8	5.1	0.360
mean annual numberamount of cold days	0.7	-0.1	2.2	0.403

4. Conclusions

Urban morphological parameters are dominating factors for the formation of the urban heat island UHI and in general of urban climate conditions. Typically, UHI is of interest in numerous studies on urban climate. For several applications, i.e. human-biometeorological analyses, UHI or UHA are not the main cause for human heat stress in summer. Related to cities, which are not influenced by thermally induced regional and local circulation systems, the radiation heat is more important in this context.

For the formation of the thermal urban climate, the configuration of morphology also plays an important role. In addition, it has to be taken into account whether the sky view factor is determined by a building or green open space in order to quantify the upper and lower hemisphere in urban structures. Another important characteristic is the orientation of buildings and the location of green open spaces and other vegetation in their position in the sky view hemisphere.

References

Baumgartner, A., Mayer, H., Noack, E.-M., 1985: STADTKLIMA BAYERN - Final report of the subproject „Thermal images of Bavarian cities“. Bayer. Staatsministerium für Landesentwicklung und Umweltfragen, Reihe Materialien Nr. 39. (in German)

Bründl, W., Mayer, H., Baumgartner, A., 1986: STADTKLIMA BAYERN - Final report of the subproject „Climate measurements in Munich“. Bayer. Staatsministerium für Landesentwicklung und Umweltfragen, Reihe Materialien Nr. 43. (in German)

Matzarakis, A. 2001: The thermal component of urban climate. Ber. Meteorol. Inst. Univ. Freiburg Nr. 6. (in German)

Matzarakis A, Mayer H, 2008: Dependence of the thermal urban climate on morphological variables. Ber. Meteor. Inst. Univ. Freiburg 17, 129-139.

Mayer, H., 1986: Objective and structure of the research project STADTKLIMA BAYERN. Mitt. Geogr. Gesell. München 71, 21-39. (in German)

Mayer, H., 1987: Results from the research project STADTKLIMA BAYERN. Mitt. Geogr. Gesell. München 72, 119-160. (in German)

Mayer, H., 1988: Results from the research program ‘STADTKLIMA BAYERN’ for urban planning. Energy and Buildings 11, 115-121.

Oke, T.R., Johnson, G.T., Steyn, D.G., Watson, I.D., 1991: Simulation of surface urban heat islands under ‘ideal’ conditions at night. Part 2: Diagnosis of causation. Boundary-Layer Meteorology 56, 339-358.

Authors' address:

Prof. Dr. Andreas Matzarakis (andreas.matzarakis@meteo.uni-freiburg.de)
Prof. Dr. Helmut Mayer (helmut.mayer@meteo.uni-freiburg.de)
Meteorological Institute, Albert-Ludwigs-University of Freiburg
Werthmannstr. 10, D-79085 Freiburg, Germany