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**INTENSITY OF THE URBAN HEAT ISLAND IN ŁÓDŹ
UNDER WINTER CONDITIONS AND ITS SIMPLE MODEL**

**INTENSYWNOŚĆ MIEJSKIEJ WYSPY CIEPŁA W ŁÓDZI
W OKRESIE ZIMOWYM ORAZ JEJ PROSTY MODEL**

In the paper the daily course of the urban heat island (UHI) in Łódź in winter was presented. Investigations were based on temperature measurements at two meteorological stations, urban and rural, in the period 26 December 1996 – 4 February 1997. 17 nights with well developed UHI were selected. During the night, temperature differences between city centre and rural areas increase at the very beginning quite rapidly and then more moderate, reaching maximum just before sunrise. Similarity between urban and rural temperature course allowed to construct simply model of the temporal evolution of the UHI intensity basing on the rural temperature course.

INTRODUCTION

Study on the modification of the local climate by urban areas has over a century history (Howard 1833) and the urban heat island (UHI) has been probably the most widely documented urban climatological phenomena (see bibliographies of Chandler 1970; Oke 1974, 1979). Many physical processes contribute to the UHI forming: heat storage in pavements and structures, altered radiation balance due to streets geometry and atmospheric pollutants, reduced low level winds due to buildings, anthropogenic heating and other. Almost all studies conducted the world over agree that maximum heat island intensity occur at night. Results differ concerning the time of peak intensity relative to local sunrise and sunset. Typically (Oke 1995) UHI intensity reaches its maximum just after sunset and next decrease slightly up to sunrise when vanish rapidly. At certain daytime hours city could be cooler than the surrounding country. The objectives of the present study are to provide another example of the diurnal variation of the UHI

strength in Łódź (central Poland) under winter conditions and construct the simple model of the nocturnal urban temperature course basing on the rural temperature route.

AREA OF INVESTIGATION

Łódź is the second biggest town in Poland as regard the population (ca 850 thousand). The total built over area is 80 km². Centre (~15 km²) is the oldest part of Łódź with 15–20 m high buildings raised about 100 years ago, new districts of blocks of flats (~15 m high) occupy about 30 km², 21 km² is covered by detached houses and 14 km² by greenery and untouched yet areas. The ground level differences in densely built area amount 55 m with the 12 km distance between the lowest and the highest points. Relatively flat area together with clear urban arrangement and absence of the special peculiarities of a city (lakes, rivers, valleys, mountains, sea, etc.) cause Łódź an exceptionally favourable place to study on urban climate. Under same circumstances (advection of the cold arctic air, windless and cloudless weather, intense emission of artificial heat) urban/rural thermal contrasts in Łódź may reach even 12°C (Kłysik, Fortuniak 1997).

DATA

The present work based on the data obtained from two stations located inside the city centre and in the surrounding country. The first station (called Lipowa) is situated in the dense built-up area at the very small square whereas the second one (called Lublinek), which represents rural conditions, is a standard meteorological station established at the airport in the south-west outskirts of the city. The rural station is situated about 6 km far from the city centre and about 20 m lower than the urban one. From the nearest buildings (detached houses) the airport station is separated by more than half kilometre wide uncovered grass area.

The data were collected with the aid of Vaisala HMP 35 temperature and humidity sensors placed in the standard instrumental shelters (2 m above the ground). The time step of measurements was taken as 10 minutes. For the present work the data from 17 nights with well developed urban heat island were selected from the period from 26 December 1996 to 4 February 1997. For almost all the nights there were the cloudless conditions with a moderate wind 2–3 m/s (average 2.4 m/s).

RESULTS

Comparison of the averaged (for all selected days) temperature courses in the night on both stations shows a great similarity of their shapes (Fig. 1). At the rural station temperature starts to fall down very rapidly about half an hour before sunset and next more slightly to the minimum just before sunrise. The urban temperature course seems to be rescaled and a little shifted picture of the rural one. In the city centre the temperature starts to decrease approximately an hour later than at airport and reaches the minimum with the similar delay. That kind of the temperature route at the analysed stations cause that the UHI grows very quickly in first hour of the night when the temperature decline rapidly. Next the intensity of the UHI enlarges more gradually but continuously up the maximum just before sunrise. After sunrise the urban/rural temperature differences quickly vanish (Fig. 2). Similar evolution of the thermal contrasts have already been reported as well in experimental as in theoretical studies (e.g. Jauregui et al. 1992; Höglström et al. 1978; Torrance, Shum 1976).

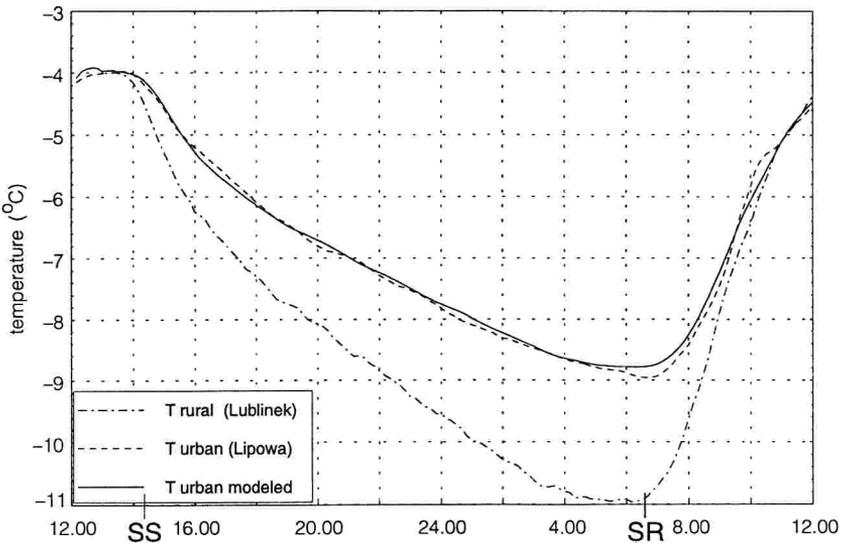


Fig. 1. Nocturnal air temperature course in winter (averaged values from 17 selected nights) at the urban and rural station in Łódź – measured and modelled values

Rys. 1. Nocny bieg temperatury powietrza w Łodzi w okresie zimowym (wartości średnie z 17 wybranych nocy) na stacji miejskiej i zamiejskiej – wartości mierzone oraz modelowane

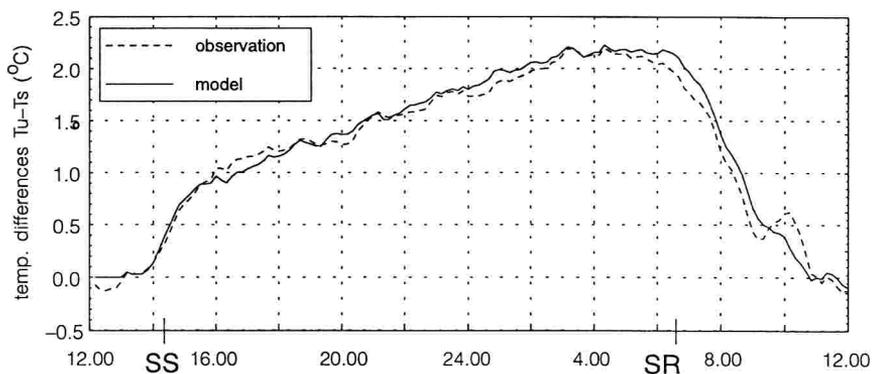


Fig. 2. Nocturnal course of the UHI intensity in Łódź in winter (averaged values from 17 selected nights) and its model

Rys. 2. Nocny bieg intensywności miejskiej wyspy ciepła w Łodzi w okresie zimowym (wartości średnie z 17 wybranych nocy) – wartości mierzone oraz modelowane

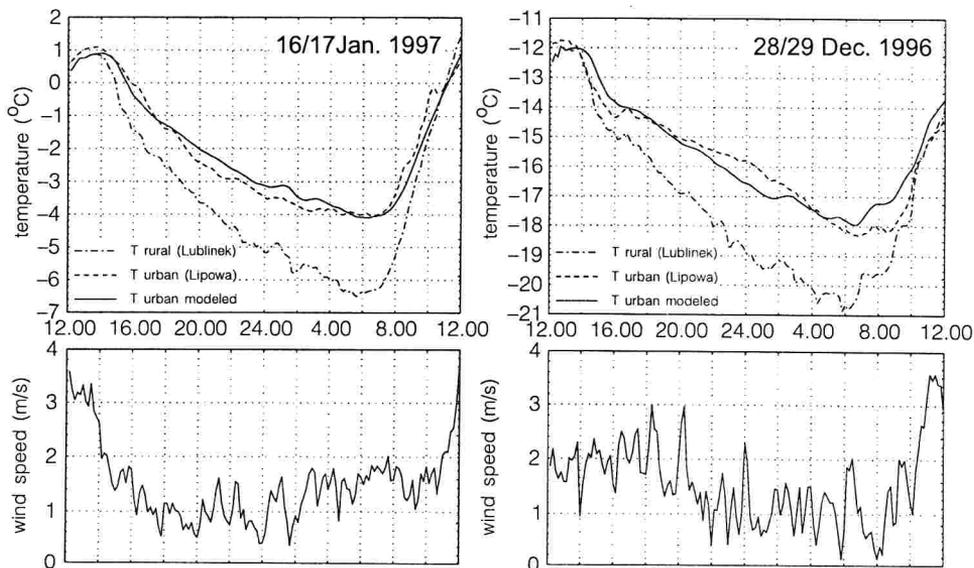


Fig. 3. Air temperature courses at the urban and rural station (measured – dashed line and modelled – solid line values) and wind speed at the rural station in Łódź in the nights 16/17 January 1997 and 28/29 December 1996

Rys. 3. Przebieg temperatury powietrza na miejskim i zamieskim posterunku pomiarowym w Łodzi (pomiar – linie przerywane, model – linia ciągła) oraz prędkość wiatru na stacji zamieskiej dla nocy 16/17 stycznia 1997 i 28/29 grudnia 1996

Such behaviour the temperature suggests a very simple model of the time evolution of the UHI strength. Because of the increased possibilities for the heat storing in the urban area the same portion of energy lost cause smaller temperature changes in the city than at the rural area. The city may be treated as a some kind of entirety with increased heat capacity. The physical properties of this entirety depend not only on the city features like its size, streets geometry, type of urbanisation but also on the actual meteorological situation. Such well known parameters as wind speed, cloudiness or vertical lapse ratio should be taken into consideration. Grater heat capacity of the city is understood here not only as the effect of increased thermal admittance of construction materials but also as a result of redistribution of the energy in the relatively thick atmospheric mixing layer over the city.

Most of the simple models (e.g. Landsberg 1981) use mentioned above parameters to determine the maximum of the UHI intensity or the urban temperature course. In the present work the temperature increments in the city, dT_u , after some time unit (taken here as 10 min) are connected with the temperature changes at rural area, dT_r , using a simple formula:

$$dT_u = A \cdot dT_r \quad (1)$$

The proportionality factor A may be some function of time but in the presented model a constant value $A = 0.69$ works well (for assumed weather conditions – cloudless sky and moderate wind speed equal 2–3 m/s). Due to taking into consideration some thermal inertia of the city the urban temperature increment at some time moment, t_i , was related not only to the rural increment in the same moment but rather to the average value over last hour:

$$dT_u(t_i) = A \cdot \left(\frac{1}{6} \sum_{k=0}^5 dT_r(t_{i-k}) \right) \quad (2)$$

Using the above formula one can calculate the urban temperature disposing a rural temperature course. The Figs. 1 and 2 show a good agreement between the model and measurements for mean conditions. Relatively small number of observations do not allow to include into the model influences of wind or cloudiness.

In spite of the simplicity the model works well not only for the averaged values but also in many particular cases. Examples of the UHI growth in selected nights of the analysed period are shown at Figs. 3, 4 and 5. For both cases presented at Fig. 3 (16/17 Jan. 1997 and 28/29 Dec. 1996) it is easy to recognise a good agreement between the model and observations. Evaluations are especially good for the night on 16/17 January then curves of the measured temperatures have almost the same shape as the lines of

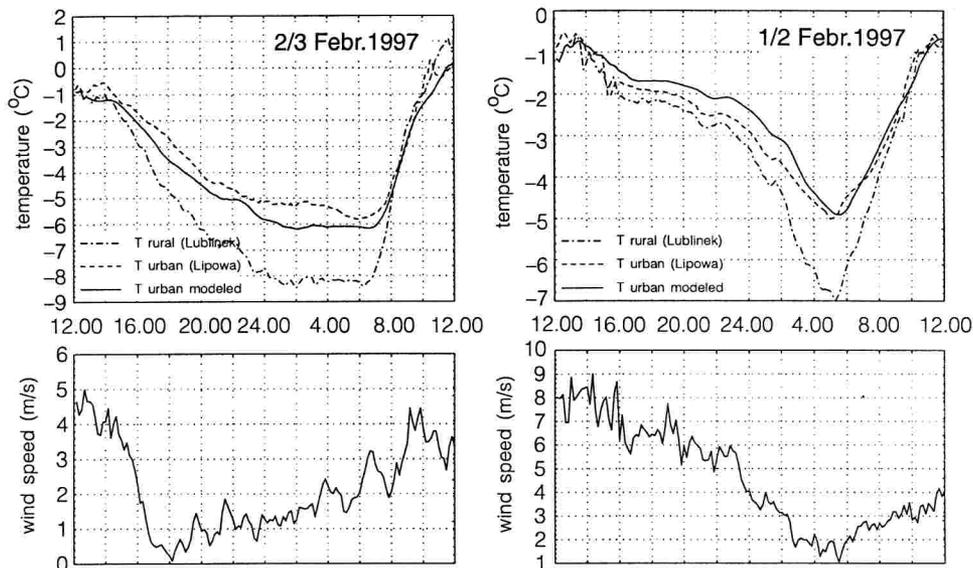


Fig. 4. Air temperature courses at the urban and rural station (measured – dashed line and modelled – solid line values) and wind speed at the rural station in Łódź in the nights 2/3 February 1997 and 1/2 February 1997

Rys. 4. Przebieg temperatury powietrza na miejskim i zamiejskim posterunku pomiarowym w Łodzi (pomiar – linie przerywane, model – linia ciągła) oraz prędkość wiatru na stacji zamiejskiej dla nocy 2/3 i 1/2 lutego 1997

averaged values. For the night on 28/29 December the model quite well estimates strength and time of the maximum of UHI intensity. However, in this case the urban cooling process persisted in morning hours when the buildings protected surface from the solar radiation and decline of the wind made air mixing difficult. The effect accelerated vanishing of the urban/rural temperature differences.

Cases presented at Fig. 4 (2/3 February 1997 and 1/2 February 1997) show more complicated temporal evolution of the UHI intensity. Rapid wind decay after sunset on 2 February enabled the temperature to drop fast in first hours of the night. In these hours rule (2) overestimated the temperature decrements leading to overlooked UHI intensity. After midnight a gradual rise of the wind speed allowed mixing processes to stop the surface air cooling, especially at the rural area. In the night on 1/2 February high wind speed terminated the UHI formation up to 3.00. Relatively good evaluation of the peak of UHI intensity with the aid of formula (2) should be in this case understood more as a result of fortunately combination of wind conditions than as a proof of the model correctness.

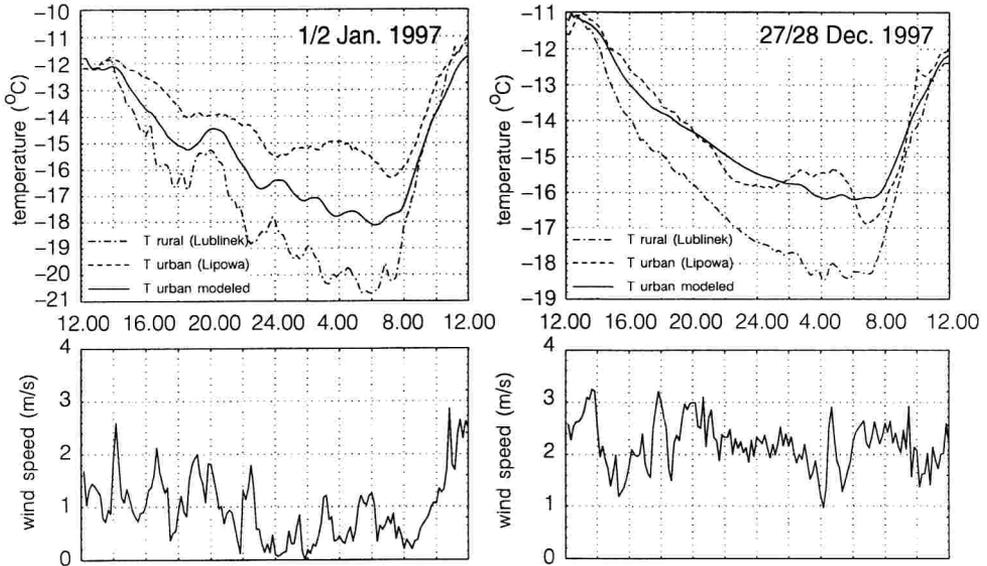


Fig. 5. Air temperature courses at the urban and rural station (measured – dashed line and modelled – solid line values) and wind speed at the rural station in Łódź in the nights 1/2 January 1997 and 27/28 December 1996

Rys. 5. Przebieg temperatury powietrza na miejskim i zamiejskim posterunku pomiarowym w Łodzi (pomiarzy – linie przerywane, model – linia ciągła) oraz prędkość wiatru na stacji zamiejskiej dla nocy 1/2 stycznia 1997 i 27/28 grudnia 1996

Last two examples (Fig. 5) present nights when the model fail. In the night on 1/2 January 1997 a weak wind allowed urban/rural temperature differences reach 5 deg. Since the proportionality parameter A had been estimated for the wind about 2–3 m/s the formula (2) undervalued UHI strength. During the night on 27/28 December 1996 the model quite well estimate smoothed temperature course on urban station. However, some perturbances of the urban temperature (increase T_u after midnight and rapid drop at 6.00) could not be approximated with the aid of the simple method (1) basing on linear relation between urban and rural temperature.

CONCLUSIONS

Temporal evolution of the urban heat island intensity in Łódź in winter differ from the most typical view for mid-latitude cities. The maximum of urban/rural temperature differences are observed here just before sunrise. The preliminary results for summer suggest that in the case of Łódź it is

a rule not only for winter conditions but all over the year. Similarity of the urban and rural temperature courses allow to construct a very simple model basing on proportionality of both variable decrements. In spite of simplicity the model quite well estimate evolution of the UHI intensity. Next work must be done to test dependence of the proportionality factor on meteorological conditions and physical features of the city.

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REFERENCES

- Chandler T. J., 1970, *Selected Bibliography on Urban Climate*, WMO 276, Techn. Note, No 55, Geneva
- Howard L., 1833, *The Climate of London Deduced from Meteorological Observation Made in the Metropolis and at Various Places Around It*, 2nd ed., 3 vols., London, J. a. A. Arch.
- Högström U., Taesler R., Karlsson S., Enger L., Högström A. O. S., 1978, *The Uppsala Urban Meteorology Project*, Boundary-Layer Met., Vol. 15, p. 69–80
- Jauregui E., Godinez L., Cruz F., 1992, *Aspects of Heat-Island Development in Guadalajara, Mexico*, Atm. Environ., Vol. 28B(3), p. 391–396
- Kłysik K., Fortuniak K., 1997, *Temporal and Spatial Characteristics of the Urban Heat Island of Łódź, Poland*, [in:] *Urban Atmosphere/Atmospheric Environment, ICUC'96* (in press)
- Landsberg H. E., 1981, *The Urban Climate*, Academic Press, New York
- Oke T. R., 1974, *Review of Urban Climatology 1968–73*, WMO 383, Techn. Note, No 134, Geneva
- Oke T. R., 1979, *Review of Urban Climatology 1973–76*, WMO 539, Techn. Note, No 169, Geneva
- Oke T. R., 1995, *Boundary Layer Climates*, Routledge, London
- Torrance K. E., Shum J. S., 1976, *Time-varying Energy Consumption as a Factor in Urban Climate*, Atm. Environ., No 10, p. 329–337

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STRESZCZENIE

W opracowaniu przedstawiono dobowy bieg intensywności miejskiej wyspy ciepła w Łodzi w okresie zimowym. Bazę doświadczalną stanowią wyniki pomiarów temperatury powietrza na dwóch posterunkach, miejskim i zamiejskim, z okresu od 26 grudnia 1996 do 4 lutego 1997. Do analizy wybrano 17 nocy z dobrze rozwiniętą miejską wyspą ciepła. W ciągu nocy różnice między temperaturą w centrum Łodzi a terenami zamiejskimi wzrastają początkowo bardzo gwałtownie, następnie łagodnie osiągają maksimum tuż przed wschodem słońca. Podobieństwo przebiegów temperatury na obu stacjach umożliwiło skonstruowanie prostego modelu czasowego rozwoju intensywności miejskiej wyspy ciepła bazującego na zmianach temperatury na obszarach zamiejskich.