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Study of the Anthropogenic Component of Urban Heat Balance

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Abstract—The contribution of the anthropogenic component into the total urban heat balance has been estimated (by the example of the city of Tomsk). The analyzed period consists of four years, from 2002 to 2007. The anthropogenic heat in the city has been subdivided into three components: burnt fuel heat (from enterprises, vehicles, and utility gas), electric energy input, and space heating. The maximum contribution into air heating is burnt fuel, and the minimum is electric energy. The total anthropogenic heat from all of the heat sources is 18 W/m^2 in the winter and 4 W/m^2 in the summer. The anthropogenic heat influx in winter months (from November to February) is from 25 to 80% of the solar radiation inflow.

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INTRODUCTION

Investigations of the urban thermodynamic regime have shown that cities are "heat islands" [1]. Many attempts to estimate the urban heat balance were made in the middle of the 20th century. The anthropogenic component of the balance was usually neglected, since this component did not exceed 3–4% of the urban heat balance input according to the performed estimates. In the second half of the 20th century, the growth of the number of residents has increased like an avalanche with the doubling of the population. Now, the Earth's population is 6.6 bln people; it annually increases by about 80 million. The part of the urban population has grown by up to 45%. Correspondingly, energy consumption has increased by several ten fold. There will be 1 bln vehicles all over the world by the end of 2009. About 2 bln tons of oil fuel is burnt annually only in car engines. Hence, we should not exclude the anthropogenic component when investigating the urban heat balance.

In this work, the contribution of the anthropogenic component into the total urban heat balance has been estimated (by the example of the city of Tomsk).

Tomsk is situated in the south of Western Siberia; it is the administrative center of Tomsk oblast. The city area is 294.6 km^2 and the population is 512 600 people. Modern Tomsk is one of the large industrial centers of Western Siberia. Industry takes the leading part in the economy of the Tomsk region; almost a quarter of the economically active population work there. About 3500 industrial enterprises work in the region's territory. The most developed branches are machine building and metal working (PA Sibkabel', Sibelektromotor; bearing, cutting tools, manometer, electromechanical, electric-bulb, radio, and other plants), chemical (chemical, chemico-pharmaceutical, and other plants), wood working (pen, match, and furniture factories), the production of building materials, and the food industry.

INVESTIGATIONAL TECHNIQUE

Anthropogenic heat in the city can be subdivided into the following components:

$$Q_F = Q_{FF} + Q_{FE} + Q_{FH} + Q_{FM},$$

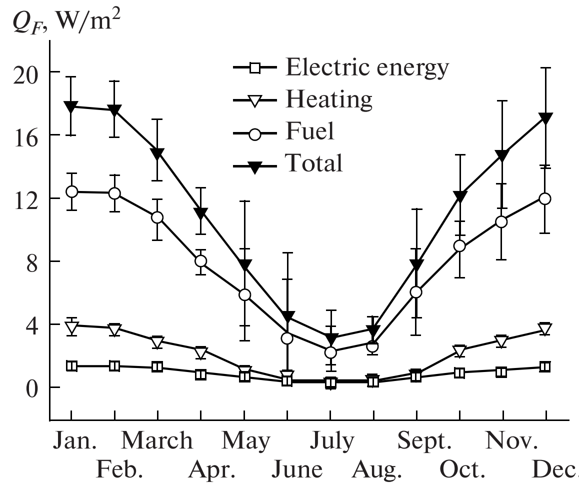

Fig. 1. The average anthropogenic heat from all of the heat sources.

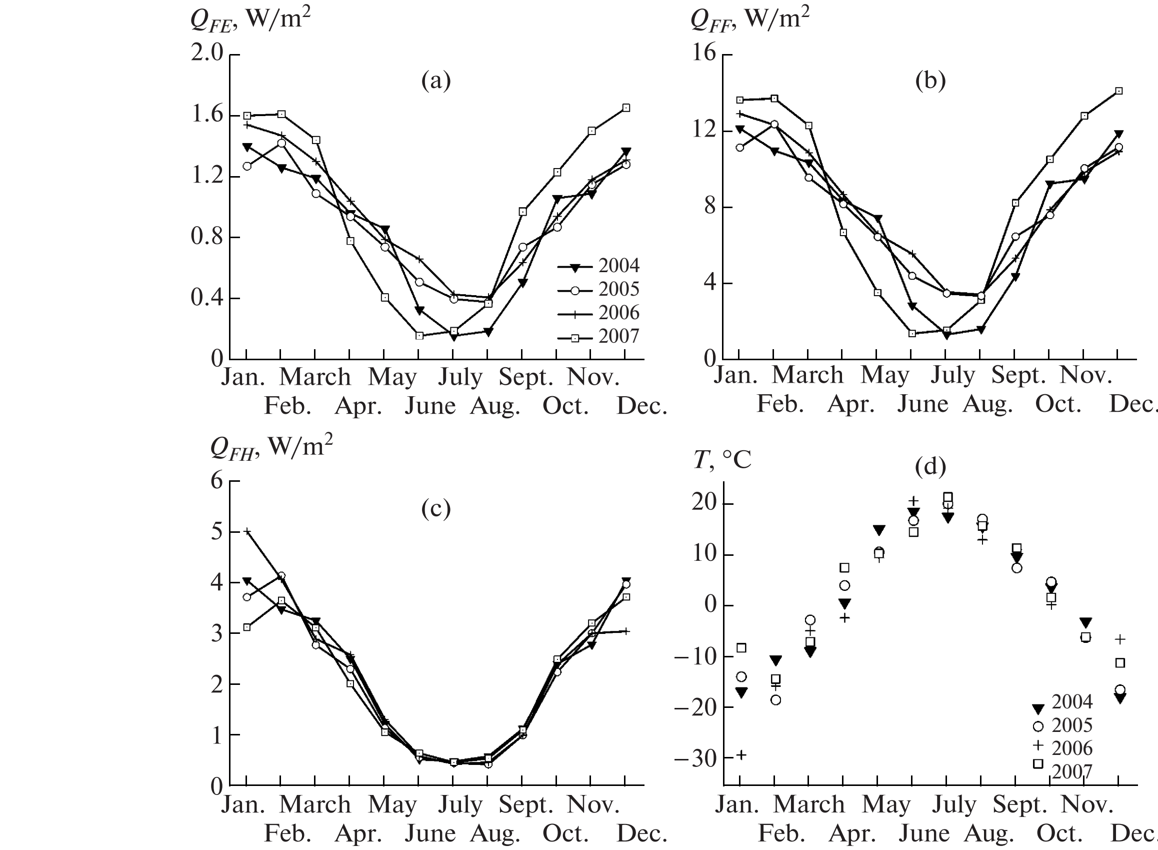

Fig. 2. Anthropogenic heat from consumed electric energy (a), burnt fuel (b), and space heating (c); monthly mean air temperature in Tomsk (d).

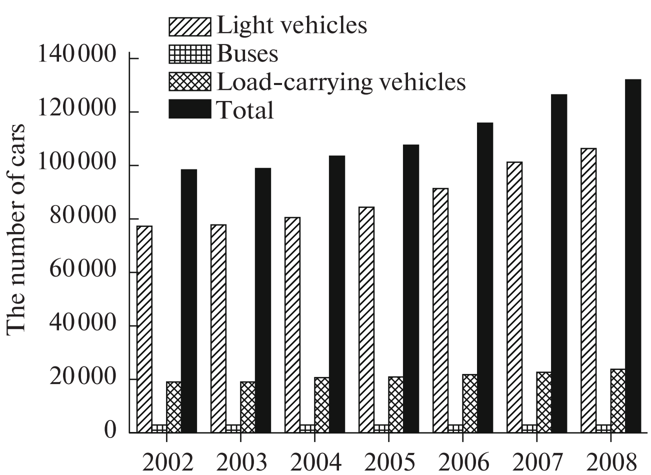

Fig. 3. Dynamics of parking lots in Tomsk.

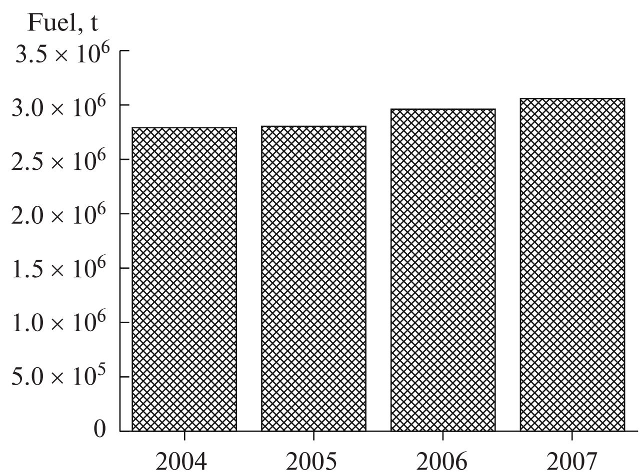

Fig. 4. Dynamics of fuel consumption by enterprises and vehicles in Tomsk.

where Q_{FF} is the anthropogenic heat from burnt fuel (enterprises, vehicles, and utility gas); Q_{FE} is the heat from consumed electric energy; Q_{FH} is those from space heating; and Q_{FM} is the anthropogenic heat from human metabolism (not considered in this work).

For estimations, we used data for Tomsk taken from the following sources:

—the amount of fuel (tons) consumed by large and small-scale enterprises and vehicles (Tomskoblstat);

—the amount of produced electric (kilowatt hours) and thermal energy (Gkal) for space heating (TGC No. 11, Tomsk Branch);

—the amount of consumed electric energy (kilowatt hours) (Tomsk Electricity Company);

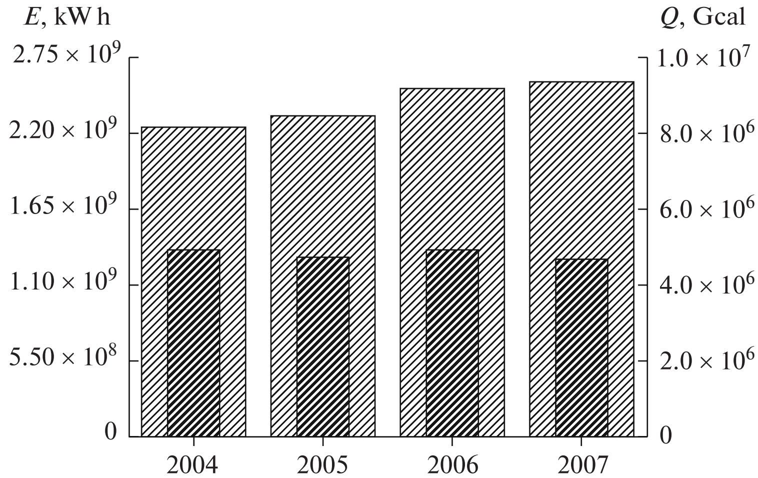

Fig. 5. Dynamics of electric power E consumption (light columns) and heat energy Q production (dark columns) in Tomsk.

—the number of vehicles (Tomsk State Traffic Safety Inspectorate).

The analyzed period consists of four years, from 2004 to 2007.

Annual data have been interpolated by months according to the electric energy consumption. Then, all of the initial data were recounted to one array and reduced to equal dimensions, i.e., the anthropogenic heat flow power per unit area (W/m^2), for convenience of comparison with the total solar flux. The conversion procedure was the following:

$$X[\text{kW h/month}] = X \times 10^3/(D \times 24)\ \text{W}$$
$$\text{and } Y[\text{Gkal/month}]$$
$$= Y \times 4.19 \times 10^9/(D \times 24 \times 3600)\ \text{W},$$

where X is the amount of produced or consumed electric energy, Y is the amount of produced thermal energy, and D is the number of days in a month.

In this work, we suppose that all of the consumed electric energy is transformed into heat.

RESULTS AND DISCUSSION

To estimate the contribution of individual components into the total anthropogenic heat flux, we first calculated the heat fluxes throughout the sample from each source and the total balance. These data are presented in Fig. 1.

It is seen that the burnt fuel maximum contributes into the total balance of anthropogenic heat. The energy income from space heating is the second factor in order of importance. Electric energy makes the minimum contribution to air heating. The production of thermal and electric energies and, hence, fuel consumption by enterprises for these purposes, depend on air temperature and the length of light. Thus, these three parameters are connected with each other and, correspondingly, have similar annual behavior. Therefore, heat release is maximal in the cold season and minimal in the summer months.

Climatic variables can vary significantly from year to year; therefore, it is interesting to consider the interannual dynamics of anthropogenic heat flux components. Such data are given in Fig. 2 separately for each component and for different analyzed years.

As is seen, the annual variations of anthropogenic heat flux from all of the sources are similar and inversely proportional to the air temperature. Figures 2c and 2d clearly show the inverse dependence of thermal energy production on winter average air temperature. Thus, e.g., a quite cold winter was in Tomsk in 2006, when the average air temperature in January was –30°C. Therefore, the release of anthropogenic heat from this source in January 2006 nearly twofold exceeded those in 2007. It is also seen (Fig. 2c) that no essential inter-

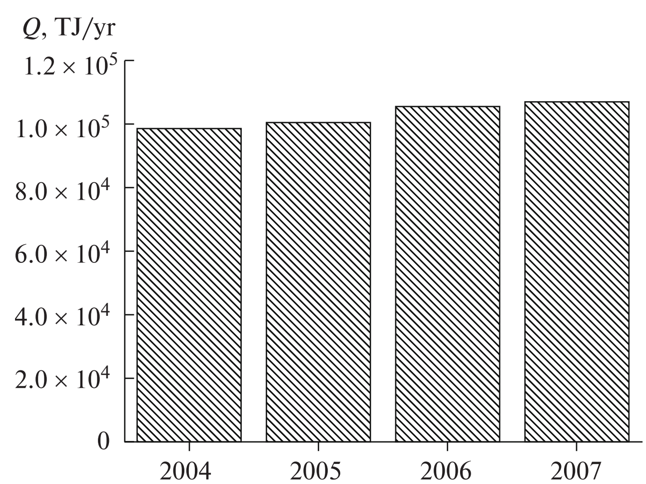

Fig. 6. Dynamics of the total heat released into the city atmosphere.

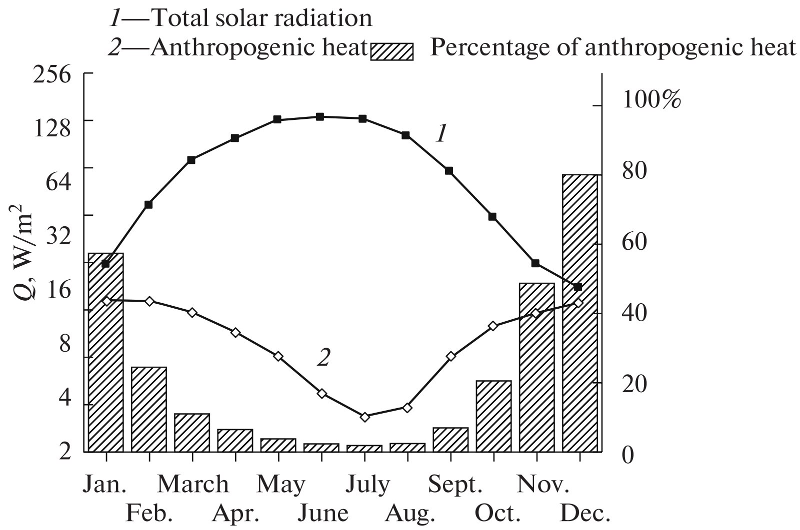

Fig. 7. Total solar radiation income and anthropogenic heat flux in Tomsk per unit area.

annual differences are observed in the summer months. At the same time, the space heating energy changes insignificantly from year to year, excluding the winter months (December–February).

Consider the trends in components of urban anthropogenic heat flux which could be prognostically significant.

The total number of vehicles in Tomsk increased by 25 000 from 2002 to 2008 (Fig. 3), mainly due to private cars.

This allows us to tell about an increase in the emission of this component of anthropogenic heat due to fuel burning by vehicles.

Figure 4 validates this conclusion; it shows the dynamics of fuel consumption by medium-size and large city enterprises and vehicles. As is seen, there is a positive trend from 2004 to 2007, and fuel consumption has increased by 10%. However, no increase in heat energy output in Tomsk is observed. On the one hand, this output is inversely proportional to the winter average air temperature in the city. On the other hand, this can well be due to energy-saving measures taken by the region government.

Consider the dynamics of electric energy consumption in the city. Here, we also observe an increase (Fig. 5) equal to 14.2% in the period under study due to the entry of new industries, which also results in additional heat release in the city.

Generalizing the above facts (Fig. 6), we can conclude that the dynamics of the total heat amount released in Tomsk air in the period under study is positive. It has been increased by 8.5% over four years. We can say nothing about a change in this trend in conditions of the current economic crisis.

To estimate the significance of the anthropogenic heat flux for the urban heat regime, compare its value with the solar radiation influx to the underlying surface using the data from [2]. Figure 7 shows the annual variations of solar radiation and anthropogenic heat influxes, and the histogram shows the anthropogenic heat adding as a percentage of the total solar radiation. It is seen that the anthropogenic heat influx in the winter months (from November to February) is about 25–80% of the total solar radiation. This is also shown in the urban thermodynamic regime: the air temperature in this period is much higher than outside the city [3].

The average annual flux of anthropogenic heat in cities (comparison of published data) [14]

City	Period	Population density (inhabitants/km^2 × 10^3)	Energy per head (GJ/yr)	Q_F, W/m^2
Manhattan (40°42′ N)	1965	28.8	169	159
Moscow (55°45′ N)	1970	7.3	530	127
Hong Kong (22°18′ N)	1971	37.2	28	33
Los Angeles (33°56′ N)	1965–1970	2.0	331	21
Fairbanks (64°50′ N)	1967–1975	0.55	314	6
Tomsk (56°30′ N)	**2004–2007**	**1.7**	**200**	**11**

Finally, compare the obtained estimates with data by other authors [4] (see the table). As is seen, the average annual flux of anthropogenic heat in Tomsk is in good agreement with similar data for other cities; the maximum anthropogenic heat influxes are observed in densely populated industrially developed cities with a cold climate. The population density in this case is very important.

CONCLUSIONS

Burnt fuel mainly contributes to the anthropogenic heat component (enterprises, vehicles, and utility gas).

The percentage of anthropogenic heat in the total solar radiation is about 25–80% in the winter months.

Hence, it is inadmissible to ignore the anthropogenic component when calculating the urban heat balance.

REFERENCES

1. G. E. Landsberg, *Klimat goroda* (Gidrometeoizdat, Leningrad, 1983) [in Russian].
2. T. K. Sklyadneva and B. D. Belan, “Radiative regime near Tomsk in 1995–2005,” Atmos. Ocean. Opt. **20** (1), 62 (2007).
3. B. D. Belan and T. M. Rasskazchikova, “Impact of the Urban Area of Tomsk on the Temperature–Humidity Regime of Air,” Atmos. Ocean. Opt. **14** (4), 294 (2001).
4. T. R. Oke, “The Urban Energy Balance,” Progr. Phys. Geogr. **12** (4), 471 (1988).