J2.7

URBAN HEAT BUDGET AND WASTE WATER HEAT DISCHARGE IN MOSCOW

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Most frequently the specific features of climate in urban areas are associated with development of the "heat island", the origin of which, as a rule, is connected with the use of energy resources for heating, hot water supply, electric energy and motor fuel consumption. An increasing of solar radiation absorbing is also considering for the northern cities. In the majority of studies anthropogenic heat balance components are quantified by means of total annual consumption of traditional energy resources (gas, petroleum residue, motor fuel, electric power) with its subsequent averaging for the whole urban area (Shcherbakov, 1987; Grimmond, 1992; Swaid and Hoffman, 1990-1991 etc.). In this case the structure and correlation of the sizes of natural and anthropogenic energy fluxes are characterized more qualitatively than quantitatively, and the spending part of the anthropogenic heat balance (heat release with household and industrial waste water) is not considered.

According to survey which sums up results of studies executed during last 20 years in the urban climatology Arnfield (2003), the equation of urban territory heat balance can be written as:

$$Q^* + QF = QH + QE + DQ_s + DQ_A, \qquad (1)$$

where Q *is net radiation, QF represents anthropogenic heat balance, QH and QE state for turbulent and molecular heat flux respectively, DQs is the heat flux storage in the ground and other surface materials, DQ_A is heat advection through the boundaries of territory under consideration. Anthropogenic heat balance (budget) according to the same source has the following form:

$$Q_F = Q_{FV} + Q_{FH} + Q_{FM}, \qquad (2)$$

where Q_{FV} represents the heat released by vehicles, Q_{FH} is heat released from stationary sources, Q_{FM} stands for metabolic heat emission. One can see no spending parts of the heat balance are detached. Accordingly we propose to introduce one more member into this equation: Q_{FW}, which is designating heat discharge with waste water, removing from the urban area by sewerage systems and through the open water flows, which in the essence can be considered as water-engineering constructions within urban frontiers. The release of part of anthropogenic heat is transmitted directly to the boundary layer of the urban atmosphere and is included into DQ_A.

Moscow is the biggest city of Russia with the great variety of energy production and consumption items and problems arising from it. At the same time Moscow got a sufficiently complete data about heat- and power supply and concerned different kinds of environmental components pollution level. That is why Moscow was taken for that heat balance analysis.

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Direct energy consumption plays the dominant role among enumerated income parts of anthropogenic energy balance. Moscow is the greatest energy resources recipient in Russia. At present all heat supply of Moscow is ensured from 16 heating and power plants (HPP) of Joint stock company "Mosenergo” - Moscow Regional Administration of Power System Management, HPP "ZIL", 39 district and minor heating plants of "Mosteploenergo" company, and also from industrial and 106 local heating boilers. The heat output of centralized heat supply sources comes to: HPPs – 35.4 GW; “Mosteploenego” and others – 13.8 GW.

An amount of thermal energy consumption directly depends on a city population, the total area of heating buildings and on characteristics of heating period – its duration, the air temperature and wind velocity. In Moscow the mean annual output of thermal energy under average heat loads during 1998–2002 was about 410–415$\times10^{15}$ J. About 70% of it was released from the collectors of "Mosenergo" and 22% was covered by "Mosteploenergo". Remaining heat was manufactured on heat HPP "ZIL" and other sources.

The annual dynamic of gas consumption is caused, first of all, by seasonal ambient air temperature variations. Furthermore, annual heat consumption depends on seasonal changes in hot water supply needs of citizens, on the temperature of water gathered from open sources and on technical needs for heating systems maintenance. The average daily summer hot water supply is of 80% of that in winter. As a result, heat requirement and consequently fuel consumption and heat emission in summer is much less than in winter (Fig. 1).

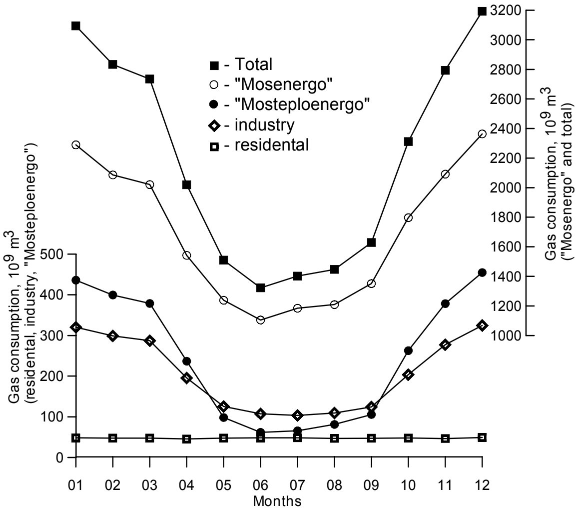

Fig. 1. Gas consumption in Moscow (1998–2002).

Average total natural gas consumption in Moscow in 1998–2002 during June–July amounts 1.3–1.4$\times10^9$ m^3, while in December-January it rises up to 3.1–3.2$\times10^9$ m^3 with average annual consumption 26.3$\times10^9$ m^3. These volumes include gas, used for production not only thermal, but also electrical energy (cogeneration), technological needs etc. Seasonal gas consumption for heating needs is about 450$\times10^9$ m^3 in winter and 60$\times10^9$ m^3 in summer i.g. there is a difference in 7.5 times.

Seasonal dynamic of heat release by "Mosenergo" which provides 75 % of thermal loads in Moscow (Fig. 2), in practice completely coincides with seasonal dynamic of gas consumption by "Mosteploenergo". So within the period under consideration the maximal heat quantity was provided to users in December (more than 41$\times10^3$ TJ/mo.), minimum, in July (about 6$\times10^3$ TJ/mo.). There is a difference almost in 7 times.

To estimate figures and to reveal places of the anthropogenic heat release to the urban environment, the aggregated diagram of urban anthropogenic heat-budget balance was elaborated (Fig. 3). All the Moscow energy production facilities, popping gas, are taken into account. Fluid combustion consists of not more than 2–3 % in the Moscow heat budget, therefore they were not considered in calculations.

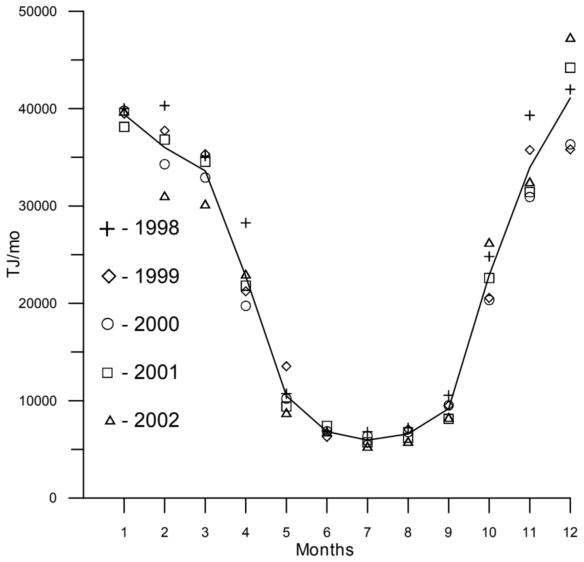

Fig. 2. Heat release to "Mosenergo" consumers

In the heat balance of the "urban area – atmospheric boundary layer" system participates not only explicit heat, produced from combustion, but also a latent heat of condensation and crystallization of water vapor, which is one of the basic products of natural gas combustion – 84.8×10^{15} J/yr, or more than 10% of explicit heat.

The crystallization of water vapor can occur from November to March, when ambient air temperature in Moscow is lower than 0°C. During this time 56% of annual gas volume is burnt. So 21.1×10^{9} kg of vapor is brought to the

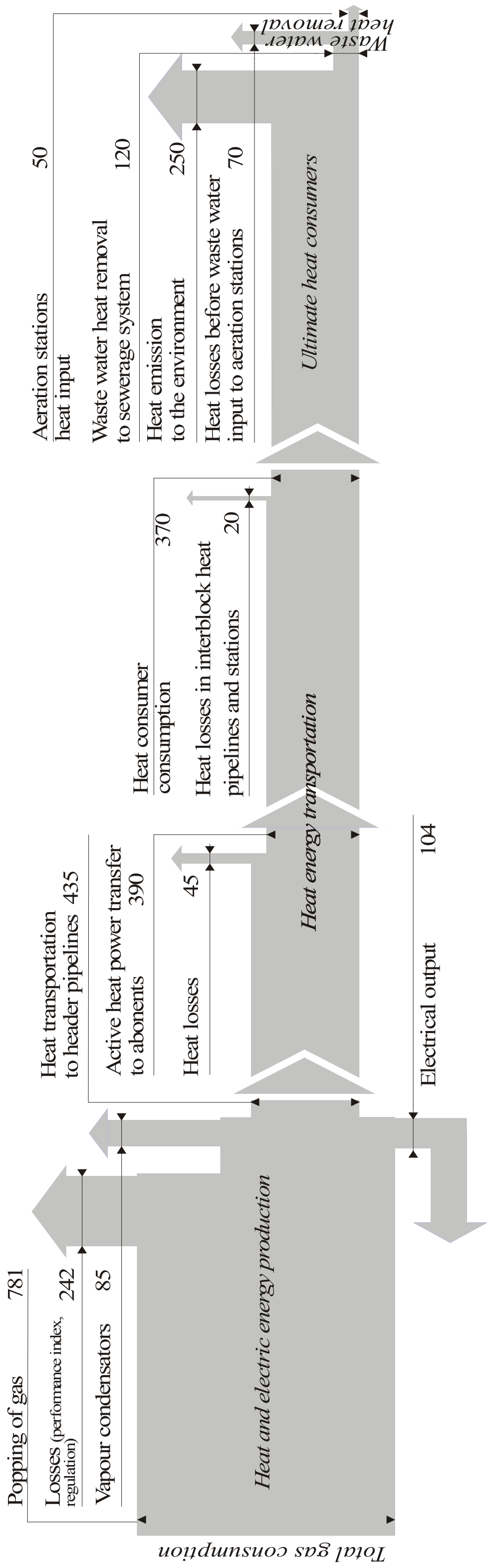

Fig. 3. Aggregated anthropogenic heat balance of Moscow (units of measure – 10^{15} J/yr)

atmosphere and its crystallization heat emission consists 7.0×10^{15} J.

It is evident that on the way from gas popping to ultimate consumption more than 60% of heat is lost, and the final consumer gets only about 30% of the total amount of heat released in the city. This low index is typical for the systems of the centralized heat supply (Sharipov, 2001), moreover it is even less for systems of separate heat production and a little bit higher for thermoelectric power stations. From 120×10^{15} J/yr of heat removed from consumers with warm wastewater, only 50×10^{15} J/yr reach aeration stations. Aeration stations (AS) discard this heat with the refined water to the riverbed of the Moscow river within city boundaries (Kur'yanovskaya AS) and beyond its limits (Lyuberetskaya AS).

In the Moscow city there is a united system of centralized electric energy supply. Thermoelectric power stations co-generate heat and electric energy. The total electric power of Moscow's stations was about 9500 MW in 2000, and electrical load for Moscow consumers - 6700 MW. On the average in the years 1998–2002 annual electric consumption was about 120×10^{15} J (33800 million kW.h.), including 15.3×10^{15} J of auxiliary and 8.8× 10^{15} J of technological and transportation losses. The annual dynamic of electric power consumption in Moscow is represented at fig. 4.

The consumption of motor fuel is one more significant item of energy consumption. The transport network of Moscow region is the largest in Russia. In 2001, Moscow motor transport park included 2 millions 348 thousand motor vehicles of all kinds. There are about 3 thousand transport enterprises. Total consumption of motor fuel per year is about 4 million tons; it was realized on 674 filling stations. The heat released from motor fuel consumption consist 160×10^{15} J/yr.

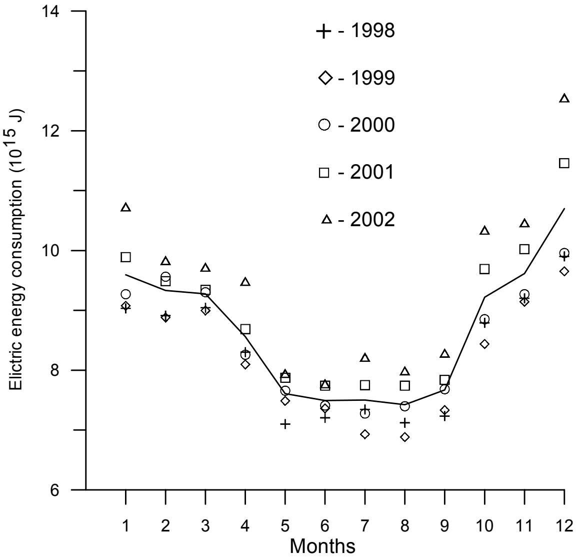

Fig. 4. Electric energy consumption in Moscow (1998–2002)

Motor fuel consumption depends on intensity of motor transport use and on the meteorological conditions, influencing on the engine warm-up time, average traffic speed, on idling time etc. The transport mobility of population has daily, weekly and seasonal cycles determining regime of motor fuel consumption. In Moscow maximum use of motor transport has place in summer and in "peak" hours about 20% of all of vehicles are in use in the city. In winter it is only 7-10 %. The daily number of vehicles in use in wintertime is about 50%, in summer it is about 90%, annual mean – 70%. As a result, in winter the consumption of motor fuel is 3 times more than in summer. In winter 5-6 ×10^{15} J/mo. released from the use of motor fuel, in summer – 18-19 ×10^{15} J/mo, with the mean annual release 160×10^{15} J.

The rest income parts of the anthropogenic heat balance are the metabolic heat release and garbage incineration. However, based on the calculations, these parts at present time do not play any significant role for the heat balance formation. Thus, in urban areas additionally to the incident radiation the active layer of ground surface obtains the additional technogenic energy inflow.

At the same time there is an expendible (outflow) component of the anthropogenic heat balance based mainly on the heat consumption with the effluents. Unessential at first glance, this expendible part of heat balance in cities situated in moderate climate, as it turned to be, is quite comparable with any of the balance income part. According to the data of statistical account of the Moskva-Oka river basin authority (Introductory note…, 2000-2001), sewage systems of the city contribute up to 90% of the Moscow river basin water. This causes significant influence on its ecosystem, including thermal pollution.

Drafty the scheme of Moscow's water supply and canalization systems can be outlined as the follows. Resources of Volga and Moscow river systems of fresh natural water are used for the city water supply. From the Volga system, water is offtaking from the channel named after Moscow not far from the village "Severnyi". Water is also taking from the stream of the Moscow River in the point placed in 0.6 km lower "Il'inskoye" village (Fig. 5). Water is transporting from diversion units to water stations for treatment and distribution to water transportation pipelines, which carry it to ultimate consumers. The portion of artesian water in total volume of water supply is negligible – not more than 1%.

Water used for hot water supply and for filling of heating systems is heating at thermoelectric power stations of "Mosenergo " and district and quarterly thermal power plants of "Mosteploenergo" and some other enterprises, where it is heated up to 130°C with the use of popping gas. Due to cogeneration of heat and electrical energy at Moscow heat power plants warm water from vapor attemperators is draining right to the Moscow river.

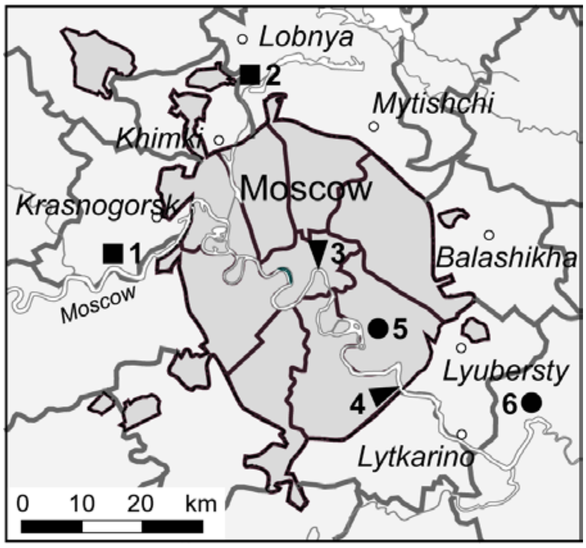

Fig. 5. Moscow's water supply points, alignments and aeration stations location. Water supply points: 1 – Iliinskoye village, 2 – Severnuy dormitory. Alignments: 3 – Babyegorodskaya dam, 4 – Oil processing factory. Sewage aeration stations: 5 – Kuryanovskaya, 6 – Lyuberetskiye.

There are two independent canalization systems in Moscow – rain- and household one. Besides that there are so called "special water users" with own water supply points and spillways to Moscow river channel. Primary flow (more than 97% volume) of refined water occurs after two aeration stations – at Kuryanivskaya station and Lyuberetskaya station consisted of Lyuberetsky and Novolyuberetsky blocks. Water flow is draining directly to Moscow river channel.

Moskva-river flow-off decreases to the sanitary required volumes of water discharge in the riverbed (5 m^3/sec) during the low period downstream the water supply point near Iliinskoye village. Within the city boundaries water discharge increases due to water supply from river Volga via Moscow channel. Moskva-river flow-off is regulated by hydroengineering constructions and reservoirs, which makes Moscow-river discharge relatively stable during the year.

In the city Moskva-river takes water of several small tributaries the biggest of which are the river Setun and river Yauza. After that the river accepts refined sewage water of Kuryanovskaya aeration station. Downstream the Moskva-river accepts some more small rivers and than it leaves the city nearby to Moscow Oil-Processing Factory. Refined sewage water of Lyuberetskaya aeration station inflows to the riverbed close to the Myachkovo village. These aeration stations accept sewage waters from the Moscow city through 4 m diameter sewage collector.

Observations of water temperature and water flow-off in the river-bed and some others water hydro-chemical characteristics according to “Surface water…” (1991) are carried out at Moscow Center for Hydrometeorology and environment monitoring at several alignments (Fig. 5).

To quantify a heat flux from the Moscow city through the Moskva-river bed and sewage water collectors the following scheme was accepted. At the alignment “Babyegorodskaya dam” and at the alignment situated on the Yauza river the water volume intaking to the city from open river-beds is recording. Initial temperature of the whole water inflowing to the city could be set by the measuring in the alignment Iliinskoye. Thus the volume of heat incoming to the city with the water in the river-bed of the Moskva-river can be estimated.

The increment of heat flux on the river’s way across the city can be quantified by volume of water, passed trough alignment “Babyegorodskaya” dam, flow-off water of the Yauza river and flow-off water of Kuryanovskaya aeration station. Temperature of this total water discharge is assumed to be equal to the temperature measured at river exit from the city at the alignment “Neftezavod” (Oil processing factory).

The heat carrying out of the city through sewage water collector to Lyuberetskaya AS should be added to the estimated increment of the heat stock trough the riverbed. This quantity of heat can be calculated multiplying wastewater flow off volume by difference between starting

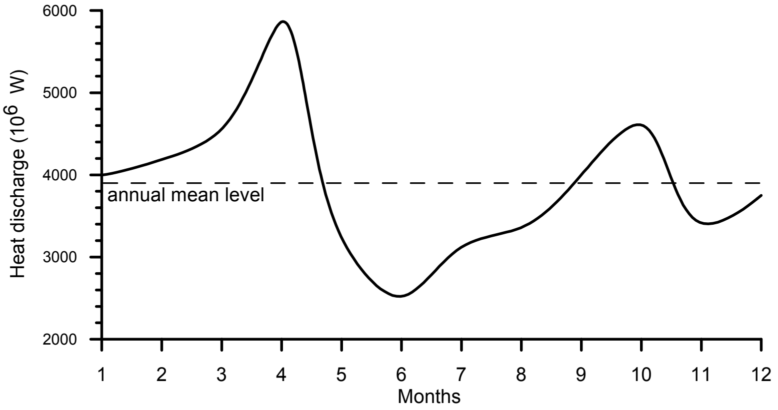

Fig. 5. Heat discharge from Moscow through river channel and sewage collectors

water temperature in Iliinskoye village and waste and water temperature in sewage collector of Lyuberetskaya aeration station.

Calculation carried out shows that wastewater takes off about 123×10^{15} J energy through the Moscow river bed. For comparison – this quantity of energy is equal to 80% of energy generated from motor fuel consumption. Minimum values of heat take off are measured in summer months – 2500–3000 MJ/sec. (Fig. 6). It can be explained first of all by initial water-supply temperature increase, therefore wastewater heat discharge decrease, secondly by heat discharge decrease around the city due to the stopping of household heating, and thirdly by total water consumption decrease including hot water consumption due to seasonal migration of citizens out of the city for a vacation time and hot water supply stopping for water pipes system maintenance. Maximum heat discharge – 4500–5800 MJ/sec. occurred in March–April due to heat consumption structure in the city, heat losses in engineering network and at consumption features.

Comparison of values obtained to receipt parts of the radiation balance has shown the follows. About 4000 MJ/sec of heat is taking off through open Moscow river channel and engineering network. Thus Q_{FW} amounts 26.3 MJ/m^2 for dwelling territory occupied 1/3 of total Moscow territory and taking into 80% of heat discharge is due housing and municipal services. This value exceeds total beam solar radiation in January (11 MJ/m^2) and amounts almost ½ of total solar radiation for the same month (63 MJ/m^2).

Value of the term Q_{FW} in heat balance of the city is not so important in summer due to seasonal decrease of heat input and increase of solar radiation arriving to earth surface. About 2500 MJ/sec is carried out from city territory in June. At the housing estate Q_{FW} amounts 15.9 MJ/m^2, total radiation amounts 612 MJ/m^2. Thus, Q_{FW} does not exceed 2.5% of solar energy that attains earth surface. Q_{FW} value regarding radiation balance turns out to be less significant at the territories occupied with manufacturing entity and transport infrastructure consuming around 20% of heat manufactured in the city.

Accordingly the research results show that the industrial energy flows turn out to be significant sources of heat comparable to radiation balance value. At the same time expenditure components caused by human activity may also reach significant values partially compensating this effect.

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