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ANALYSIS OF "HEAT ISLANDS" MONITORING PRINCIPLES

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The phenomenon of urban heat island and methods of its examination are studied in this work. The urban heat island (CHI) is determined by positive temperature anomaly located between build-up area and its surrounding. For detailed analysis of heat island of specific territory different methods can be used. Today there are 3 research methods that are often used: transformational, with help of observation network and remote sensing materials. The most promising is a method of analysis and de-coding of satellite data. The target of the work is analysis of temperature anomalies within the borders of Kyiv city with the help of remote sensing data (satellite data of Landsat missions). In this research initial materials were space images of satellites Landsat 7, Landsat 8. The build-up part of Kyiv territory is characterized by essential thermal anomalies. The last ones might be subject to long heating period during which certain thermo-dynamic regime was established: heat that comes through underground pipelines is dispersed by buildings and this is reflected on the temperatures map. With almost identical meteo-conditions of remote sensing data acquisition (but during different seasons and with different duration of heating season) it becomes possible to do quantitative evaluation of thermal anomaly that appears over the city. Introduction of additional data (such as information about weather-conditions, land use / land cover classification, results of radio-location studies, investigations of atmospheric phenomena and processes) will allow to develop unified and special methodologies designed both for thermal pollution control and for increase of energy efficiency of thermal networks and infrastructure of inhabited areas. Existing system of heat island monitoring does not provide conduction of systematic inspections of the territories in order to find temperature anomalies that may negatively impact ecology of urban environment and population health.

Keywords: urban heat island, microclimate, temperature anomalies, thermal field, urban/housing density.

Introduction. Today the Earth population is around 7,5 billion people. Herewith according to UNO more than a half of population is located in cities and according to forecast it's quantity will increase up to 66 % till 2050 [16]. The processes of growing urbanization are happening in Ukraine as well despite of decline in total population quantity (170K for 2016). According to State Statistics Committee the city population part accounts for 29 mln 584 thousand people (69,19 %) as of 1st of January 2016 and it continues to increase.

The growing urbanization and intensive expansion of cities infrastructure causes disruption of ecological balance, which threatens comfortable population habitation, causes powerful anthropogenic impact on all ecosystems components, leads to appearance of heat pollution – "heat island" (Eng. Urban Heat Island – UHI) [9, 12, 15] which are the results of accumulation of microclimate changes connected with anthropogenic transformation of urban territories.

Heat pollution is a serious problem, directly influencing ecological, geological environment and indirectly is impacting the relief. The powerful abnormal temperature fields appear around the construction which generate thermal processes. First of all, it relates to different thermal batteries, chimney pipes, heat networks and other constructions of TPP (thermal power plant) and enterprises technological cycles of which may cause surface overheating up to 50 °C and sometimes up to 80–100 °C. According to scientists' estimations the temperature of the solid and subsoil waters might exceed by 10–15 °C within the limits of certain areas.

Maximum temperatures are observed on the areas of metropolitan constrictions, in the zones where cooling systems with water-exchange are functioning, on the territories of laying out the heat pipelines and gas pipelines. There are quite intensive soils warming up, especially their lower horizons that are observed over heat- and gas pipelines. At a depth of 0,5 meters during summer time the soils temperature may go up to 40 °C and higher.

Long lasting action of heat sources breaks down the temperature regime of lithospheric space at the depth of 30–40 meters (sometimes more) increasing (or decreasing during artificial freezing of soils) temperature of rock formations and subsoil waters, which in its turn changes physicomechanical, physicochemical characteristics of the soils. First of all, the soils drying-out, breakage of structural links in them and weakening of power takes place. Such ecological changes lead to faster damage of machines and buildings designed for work in the conditions of normal temperature of geological environment, to issues from drainage structures (water pipelines, heating plants, canalizations) and often even to fall and subsidence of surface over these constructions, which at the end may create ecological problems in the city.

As researches prove [11] in the metropolises e.g. in New York the temperature on the surface of city environment is +17 °C more than temperature in the suburbs which negatively impacts the health of population. Especially threatening are zones of temperature anomalies during summer period when temperature can additionally grow. On the other hand, the increase of temperature in metropolises causes additional energy expenditures for climate-control systems, speeds up insects reproduction, metals corrosion, stimulates release of eco-toxicants in the results of chemical reactions.

The above stated proves that researches addressed to evaluate temperature rises, parrying risk of overheating of city surface territories, growth of energy expenditures, monitoring of atmosphere air are very essential.

For monitoring of "heat islands" the following methods of investigations are used: infra-red cameras, with the help of observations network and space images in infra-red band [3, 5–7, 8, 10, 13].

Object of investigation – the surface of Kyiv city environment where there are heat contrast objects.

The target of the work – analysis of temperature anomalies in the boarders of Kyiv city according to data of infra-red measuring and with the help of remote sensing data (satellite data of Landsat missions) with further determination of ecologic-problem districts and areas of Kyiv city environment with the help of geo-information technologies.

Tasks of investigation – analysis of the reasons of temperature anomalies and development of recommendations to decrease these anomalies, setting the

maps of temperature anomalies of surface according to satellite data of thermal field.

Analysis of latest researches. The following authors dedicated their surveys to investigation of city heat islands with the help of thermal-vision systems – by V. Bozhenko, V. Shklyarskyi, F. Sizov, V. Zabudskyi, O. Holenkov, S. Kravchenko, B. Kornienko, the others with have done it with the help of materials of thermal space shooting – V. Hornyi, A. Tronin, B. Shylin, Y. Baldin, M. Hryshchenko, I. Labutina, V. Lyalka, S. Stankevich, V. Filipovych, A. Krylova, B. Busyhina, I. Harkusha. In the works of these authors there were the topics of thermal GPS survey application examined during investigation of energy efficiency of city infrastructure and ecological condition of big cities.

The summary of the main part. Modern cities create "heat islands" – territories inside cities which are remarkable by increased temperatures of air, soils, water in comparison to city suburbs (Fig. 1).

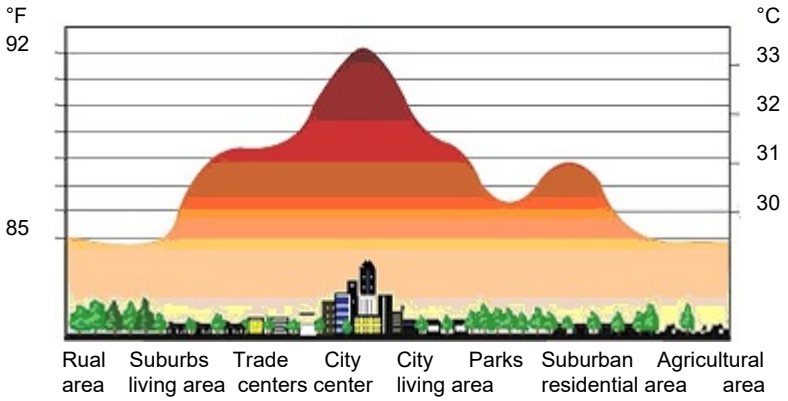

Fig. 1. Creation of "heat islands" and temperature distribution after noon

Appearance of "heat island" is caused by several factors.

1. Factor 1 – Intensive city area construction and "sealing" of the surface of ground coating with tight moisture-permeable road coatings (asphalt, cement slabs, gravel, etc.), the reduction of areas with open soil and greenery. Tight materials used in construction activities accumulate thermal energy and create moisture non-penetrating underlying surface, while configuration of construction provides higher absorption of solar radiation. As a results roofs and walls of buildings, paving and asphalt coating, other elements of city buildings absorbing solar radiation during the day become hotter unlike soil and greenery and give away warmth to air mainly in the evening. As a result, the air temperature in cities is by 70–80 % higher than the temperature in the countryside. And this difference increases with growth of metropolises construction.

Precipitations that fall on roofs, sidewalks, roads often go to the artificial drainage systems. It also causes distortion of the natural processes because of a small evaporation and low humidity and increases upward flow of actual heat in the structure of the radiation balance surface under anthropogenic infrastructure. If rural solar energy is spent on evaporation dew, transpiration, etc. in the morning, in the city and especially large one it is directly absorbed by buildings. Besides due to city territory that is heated more than the surrounding area and is characterized by a greater roughness, convection over the city increases and creates more clouds, which in turn causes a reduction in the number of hours of sunshine and the number of clear days. There is also an increase in rainfall over the city.

2. Factor 2 – Atmospheric pollution from industrial facilities sphere, transport and other sources. Any city is a concentration of industrial, energy, transport, polluting the air with various impurities, particles, smoke, gases and aerosols. A lot of different pollen and gaseous contaminants go to the atmosphere. The high concentration of pollutants in the city atmosphere especially on large the roads, streets with heavy traffic and industrial facilities leads to degradation of ecological conditions and comfortable living of urban population.

With a stable stratification of the atmosphere especially at temperature inversion, the smoke will be accumulated in atmospheric boundary layer in such quantities that will cause negative physiological effect and sometimes mass poisoning. There are examples of the harmful impact of smoky air in the metropolises with the assistance of territory relief to it, such as when industrial waste – poisonous fumes and gases sometimes accumulate in the lower atmosphere.

City streets systems and squares lead to the changes of air directions in the cities. Air is mainly directed along the streets. Generally, the air speed is decreased while on narrow streets and crosses it increases causing dust whirlwinds and storms.

Air pollution influences radiation relocation and increases generation of condensation nuclei which causes creation of cloud droplets. Simultaneously diffuse sky radiation growth is happening which together with anthropogenic heat emission leads to appearance of local "greenhouse effect".

3. Factor 3 – Energy dissipation which is worked out and goes for heat input needs, transport service and technological processes in environment and soils that cause its heating. Among biggest anthropogenic sources of heat pollution of surrounding areas there following objects should be pointed out – heat power engineering and heat input facilities, steel industry, transport, enterprises where heated water or heated air, steaming or cooling towers are used as well. Such emissions from steel industry enterprises are have a temperature of 30–400 °C, and sometimes about 800 °C. In some industrial areas the concentration of thermal energy due to industry has increased significantly; over the industrial centers where thermal anomalies are a few degrees higher than norm hot halos appear and they are well determined on satellite images of the earth's surface.

4. Factor 4 – Formation of dead air zones that appear on the constructed areas and which prevent turbulent mixing of the atmospheric layer and the removal of excessive heat in the atmosphere layers lying above, unlike undeveloped areas;

5. Factor 5 – Specifics of relief. In conditions of complex relief various local air circulations impact the development of "heat island".

6. Factor 6 – Changes of natural hydrological cycles of rivers and reservoirs which flow though cities or near cities, draining of wetlands within city boundaries as well.

A large contribution to the appearance of "heat islands" does heat power engineering. The heat emissions are one of the major factor in the interaction of heat and power facilities with the environment, including the interaction with atmosphere and hydrosphere. Heat emission occurs at all stages of chemical energy conversion of organic substance or nuclear fuel for further generation of thermal energy. Big part of the heat received by cooled water in the condensers of steam turbines is transmitted to the cooling buildings, ponds, drains and from there into the atmosphere. The temperature in place of heated water discharge rises which leads to increase of average surface of water bodies, and therefore the atmosphere air temperature over the heat power plant increases due to energy emitted by this plant into the atmosphere.

Electric power plants can raise the water temperature compared to the surrounding area by 5–15 °C. If the temperature in the water basin is 16 °C the temperature of wastewater on station will be from 22 to 28 °C. In summer period it may even reach 30–36 °C.

Increase of water temperature is able to break the structure of water basic flora. Peculiar to cold water flora are changed for heat-loving plants and with a time because of high temperatures are pushed out at all.

The research of "heat islands" with the help of thermos-vision cameras. Among modern instruments of investigation of city infrastructure objects conditions the major role play techniques of thermal monitoring which provide visualization of thermal condition of the object thanks to transformation of infrared rays into electric signal which is further used for analysis of condition of subject under research which gives a possibility to solve the tasks of remote and non-contact control in non-reachable infrared (IR) range of radiation spectrum for human vision.

Thermovisor or infra-red camera – is a device for image acquisition in infra-red range of wave-length. Exactly in this range there is a maximum emissivity capacity of bodies which have regular for us temperatures (-20 … +40 °C). With the help of thermovisor it's possible to immediately measure heat flow from tens of thousands of object points or in other words to receive it's temperature field (thermograph).

Thermographs are the basic for analysis of received information about object's thermal state.

Thermovisors are used for military targets, energy audit, evaluation of building structures quality, detection hidden defects of construction, disorder of heat insulation of shielding constructions, because of mistakes of engineering and construction, violation of manufacturing technologies of construction materials, mistakes and violations of technologies during building constructing, while seeking for heat leakage of heat pipelines and for diagnostics of electric equipment.

Any objects emit heat and during thermos-vision inspection with the help of thermos-vision camera the operator gets so called thermal images of objects (Fig. 2) which reflect the distribution of temperatures and the heating of their surfaces. The thermos-vision camera shooting is usually performed in case of inside and outside temperature difference not less than 10–15 °C. The most exact data is received in process of procedure execution during cold months of autumn, spring and winter.

Analysis of received thermographs allows to determine various defects that happened during construction. As an example in the Fig. 3 there some common defects of buildings and structures that are found with the help of thermal control method.

Shooting with the help of thermovisor indicates the "painful" points of the building. On thermograph they are shown with bright yellow shine. The higher shine the more heat is emitted by the building.

Fig. 2. Getting thermal image of objects with the help of thermovisors

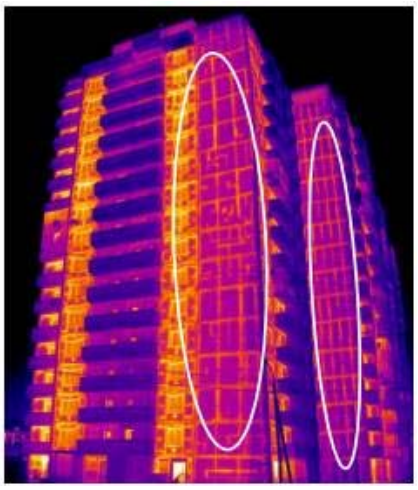

Fig. 3. Common defects of buildings and structures that are found with the help of thermal control method [5]

Investigation of "heat island" with the help of Earth Remote Sensing (ERS). Materials of ERS in infra-red range opened wide opportunities to solve many tasks of the industry, namely in military reconnaissance, meteorology, tectonics, oceanology, to look for minerals, monitor environment, for energy-economy, cartography of Earth thermal fields, determination of sea surface temperature, monitoring of natural disasters (seismic activities, volcano eruptions, monitoring of forest fires as well), to observe in time and space their development, to see specifics of space distribution of "heat islands", to evaluate heating effect of various city objects one on the other.

In modern thermal infra-red images one can find reflections of Earth surface objects hidden on these images in other ranges of spectrum and invisible for human vision. Thermal images deliver as well other important information which is displayed in relative contrasts of brightness of the sounding objects with different temperature.

Modern satellite sensors (of civil use) allow to receive special resolution on the level of tens hundreds meters on 1 pixel: 90 m (Aster), 60 m (Landsat 7), 100 m (Landsat 8). Such images contain quality-new information about landscapes of underlying surface and its geographical characteristics.

In this research initial materials were space images of satellites Landsat 7, Landsat 8. Images from Landsat satellites are one of the most common materials of Earth remote sounding in researches on regional level. This also concerns images in thermal infra-red range. Such images allow to see inner space structure of city heat islands, trace development in time and space of local thermal anomalies, evaluate thermal impact of various city objects one on the other. In researches of city heat islands images from Landsat satellites are used both as main and additional material.

As an example on the Fig. 4 there is an intensity of thermal emission presented (on wave-length 11,45 micrometers) within Kyiv city territory and adjacent agglomeration. Image was received with the help of spectroradiometer ETM+ (satellite Landsat 7) 28/03/2003.

Fig. 4. Image of Kyiv city territory in thermal infra-red range

For investigation of special peculiarities of heat islands one uses various types of classifications according to space images in thermal IR range. As a rule, such methods are used for examination of "lands use" and creation of "maps of land covers" (land cover/ land use). Often images in different spectrum ranges are used in land cover/ land use researches, one of them is thermal range. During analysis of links between types "land use" and thermal anomalies land cover/ land use maps are developed. It is not one time mentioned that there is an interconnection between heat island structure and characteristics of lands surface (land cover/land use), as well as the opportunity to use thermal images as a trusted source of information for getting information about lands use specifics.

Important part of scientific works with the topic of special peculiarities of heat island examination are occupied by various types of thermal characteristics surface modelling and exclusion of thermal emission parameters. Most often the task of getting thermal images of land surface temperatures is investigated (LST). LST figure is possible to get while using the equipment that executes shooting immediately in several thermal channels (algorithm of "split window method, SWM).

As well it is important to take into account space-time dynamics of heat islands both seasonal and daily. Examination of daily dynamics allows quite fully to evaluate thermal characteristics of various city objects, change of its temperature amplitude during a day, define objects which formulate thermal anomalies in different time of a day, define time of a day which best suits for thermal shooting with this or that aim. Nevertheless, during use of thermal images from Landsat satellite it is difficult to illustrate daily change of heat island with the help of space images because of specifics of satellites' orbit (orbit is solar-synchronous and thus satellite goes over certain place at the same time of a day). Night images from Landsat satellites are in archives but there are not so many of them. The investigation of seasonal dynamics allows to reveal heat island change of structure during a year, local thermal anomalies specifics dynamics, thermal characteristics of anthropogenic and natural objects in the scale of the whole year.

Important role should be dedicated to comprehensive researches in which it is necessary to combine LST images creation, examination of seasonal and daily dynamics in cities with different climate conditions, statistical analysis, links between LST, NDVI images and land cover/ land use

maps, investigation of thermal flows. Such types of researches give multisided evaluation of heat islands and are able to make essential contribution to city climate urbanization impact study.

Summarizing short overview of approaches of urbanized territories investigations on the basics of thermal images it is important to mark that today the most common is an approach first of all based on modelling and recovering parameters of underlying surface, and less examination of geographical specifics of the temperature field (and its changes) of anthropogenic and natural objects.

Let's study as an illustration the territory of Kyiv city (within boarders indicated on Fig. 4). Let's create RGB-composite in natural colors (NCC – Natural Color Composite) according to a set of multi-spectrum data LE71810252003087ASN00 received by spectroradiometer ETM+ (Landsat 7 satellite) on 28/03/2003 (Fig. 5). On the image it is clearly shown types of land covers as well as the regimes of their use are identified.

On Fig. 6 it is presented brightness temperature of the surface proportional to energy of thermal emission of land-based objects.

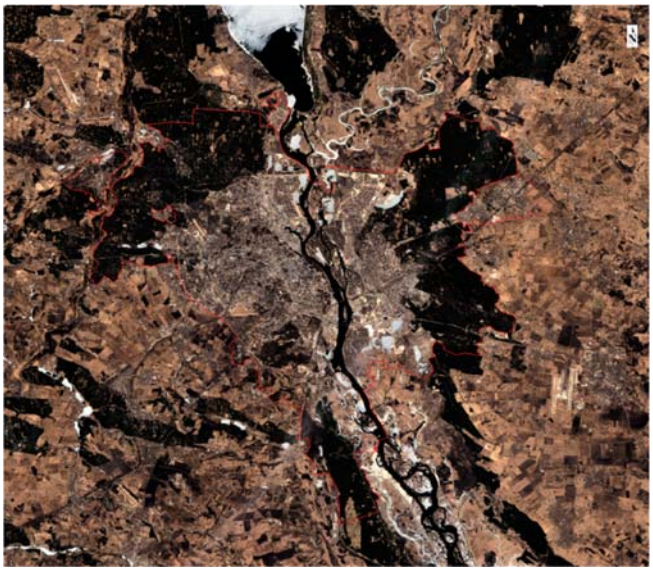

Fig. 5. Kyiv city territory and its adjacent agglomerations valid as of 28/03/2003

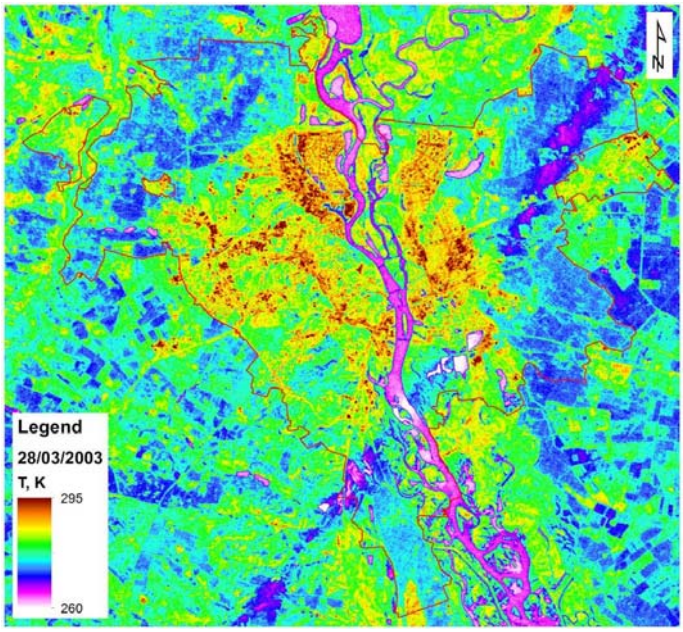

Fig. 6. Brightness temperature of the surface valid as of 28th of March (end of heating season). LE71810252003087ASN00

As clearly seen on Fig. 6 build-up part of Kyiv territory is characterized by essential thermal anomalies. The last ones might be subject to long heating period during which certain thermo-dynamic regime was established: heat that comes through underground pipelines is dispersed by buildings and this is reflected on the temperatures map. Separately it's worth mentioning such a detail of this image – along the whole scene from northern east to southern west there is a line of low temperatures. This is inversion trace from jet engine airplane which is gradually dispersing in the atmosphere and has no relation to land surface temperatures.

On Fig. 7 for comparison the situation at the beginning of heating season is shown (the year is different, 2014, but this is not crucial as the beginning and the end of heating season each year is not changing).

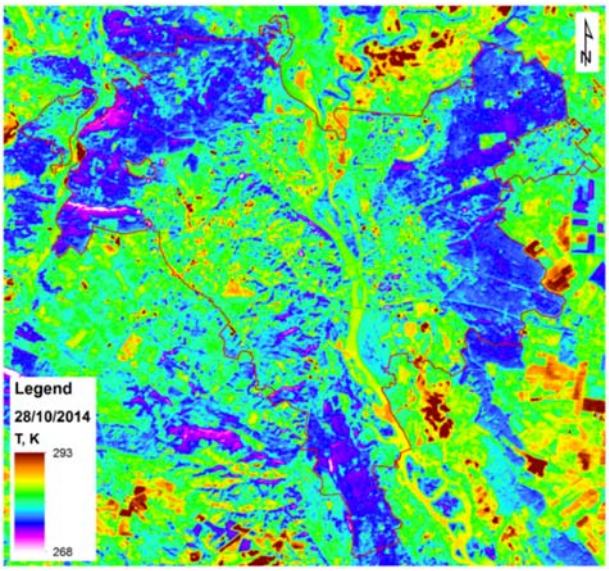

Fig. 7. Brightness temperature of the surface valid as of 28th of October (beginning of heating season). LC81810252014301LGN02.

As seen on Fig. 7 actually within the same temperature range the special distribution of temperatures filed is absolutely different. Background thermal indicators of Kyiv city are almost the same as general background indicators (if we are speaking about open areas; the areas with relatively low temperatures marked with blue tones correspond to forests – see Fig. 5). It's obvious that absence of contrast "thermal spot" within city boarders is caused firstly by the fact that heating season has just begun and residential fund objects and infrastructure were not fully heated and secondly by the fact that natural objects (e.g. water in Dnipro river) have not got cold.

The comparison of thermal picture valid as of 28th of October (beginning of the heating season) and 28th of March (end of heating season) are reasonable and correct, especially from the view of identity of meteorological conditions exactly for these dates [4] (Table 1).

Table 1. **Meteo-conditions of ERS data acquisition**

ERS data	Date and Time of meteo-characteristics determination	T, °C Air temperature at height of 2 m above the surface	Td, °C Dew-point temperature at height of 2 m above surface	Te, °C Effective temperature
LC81810252014301LGN02	28/10/2014 12:00	+8,7	–7,4	+10
LE71810252003087ASN00	28/03/2003 12:00	+8	–3	+7

With almost identical meteo-conditions of ERS data acquisition (but during different seasons and with different duration of heating season) it becomes possible to do quantitative evaluation of thermal anomaly that appears over the city. For this we find the difference between temperature surfaces of indicated dates (Fig. 8).

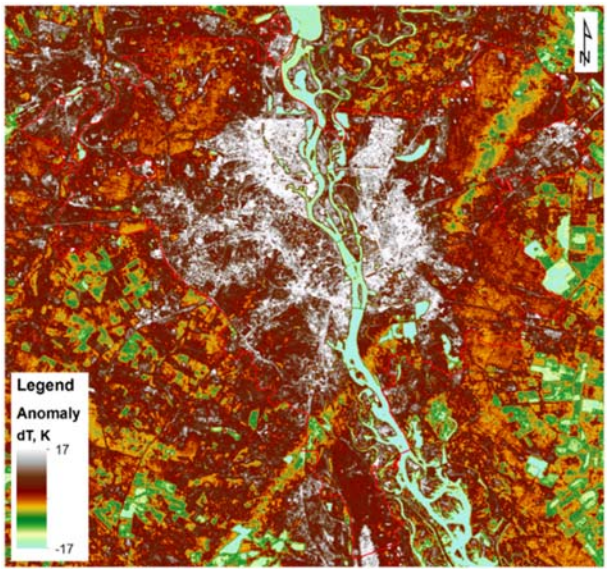

Fig. 8. Characteristics of thermal regime change in Kyiv city during heating season (vs surrounding areas)

Given example confirms earlier stated thesis regarding considerable potential of satellite thermal shooting and circle of tasks which are solved with the help of its results. Introduction of additional data (such as information about weather-conditions, land use/land cover classification, results of radio-location studies, investigations of atmospheric phenomena and processes) will allow to develop unified and special methodologies designed both for thermal pollution control and for increase of energy efficiency of thermal networks and infrastructure of inhabited areas [12, 14, 17].

Conclusions. Conducted analysis of condition of ecological and anthropogenic safety of engineering cities and villages infrastructure generally confirms absence of comprehensive approach for defining considerable quantity of natural and anthropogenic threats to safety of life activity in big cities of Ukraine.

Existing system of heat island monitoring does not provide conduction of systematic inspections of the territories in order to find temperature anomalies that may negatively impact ecology of urban environment and population health.

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АНАЛІЗ ПІДХОДІВ ЩОДО МОНІТОРИНГУ "ОСТРОВІВ ТЕПЛА"

Розглянуто феномен міських "островів тепла", причини їхньої появи і методи дослідження. Міські "острови тепла" визначаються позитивною температурною аномалією, яка локалізується в межах забудованої території та її околиць. Для детального аналізу "острова тепла" конкретної території можуть використовуватись різні методи. Сьогодні найчастіше використовують три основні методи дослідження: транспортний, за допомогою мережі спостережень і за матеріалами дистанційного зондування. Найбільш перспективним є метод аналізу і дешифрування супутникових даних. За мету даної роботи покладено аналіз температурних аномалій (що утворюються протягом опалювального періоду) у межах міської агломерації м. Києва на основі даних дистанційних зондувань (даних, отриманих за допомогою супутників місії Landsat). Забудована частина міста характеризується суттєвими тепловими аномаліями.

Останні обумовлені тривалим періодом нагріву, протягом якого встановлюється певний термодинамічний режим: тепло, яке надходить від підземних трубопроводів, розсіюється будівлями, що відображується на карті температур. Значна частина тепла поглинається і згодом розсіюється ґрунтовим середовищем. За майже ідентичних метеорологічних умов збирання даних дистанційних зондувань (але в різні сезони і за різної тривалості опалювального періоду) стає можливою кількісна оцінка термічної аномалії, що утворюється над містом. Залучення додаткових даних (таких як інформація про погодні умови, результати класифікації за типом землекористування і типом відбивних поверхонь, результатів радіолокаційних досліджень, досліджень атмосферних явищ і процесів) дозволить розробити єдині й спеціальні методології, призначені як для контролю теплового забруднення, так і для підвищення енергоефективності теплових мереж та інфраструктури населених пунктів. Існуюча система моніторингу "теплових островів" не забезпечує можливості проведення систематичних перевірок територій з метою відшукання теплових аномалій, які можуть негативно вплинути на екологію міського середовища та здоров'я населення.

Ключові слова: міський острів тепла, мікроклімат, температурні аномалії, тепловий діапазон, щільність забудови.

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АНАЛИЗ ПОДХОДОВ К МОНИТОРИНГУ "ОСТРОВОВ ТЕПЛА"

Рассматривается феномен городского "острова тепла" и методов его изучения. Городской "остров тепла" (ГОТ) определяется положительной температурной аномалией, которая локализуется в пределах застроенной территории и ее окрестностей. Для детального анализа острова тепла конкретной территории могут быть использованы различные методы. В настоящее время применяют три основных метода исследования: транспортный, сети наблюдений и по космоснимкам. Наиболее актуальным является метод анализа и дешифрирования космоснимков. Целью данной работы является анализ температурных аномалий, образующихся на протяжении отопительного периода в пределах городской агломерации г. Киева по результатам данных дистанционных зондирований (данных, полученных с помощью спутников миссии Landsat). Застроенная часть города характеризуется существенными тепловыми аномалиями. Последние обусловлены длительным периодом нагрева, во время которого устанавливается определенный термодинамический режим: тепло, которое распространяется от подземных трубопроводов, рассеивается строениями, что и отображается на карте температур. Значительная часть тепла поглощается и рассеивается грунтовой средой. При практически одинаковых метеорологических условиях сбора данных дистанционных зондирований (но полученных в разные сезоны и в условиях разной длительности отопительного периода) становится возможной количественная оценка термической аномалии, образующейся над городом. Привлечение дополнительных данных (таких как информация про погодные условия, результаты классификации по типу землепользования и видам отражающих поверхностей, результатов радиолокационных исследований, исследований атмосферных явлений и процессов) позволит разработать единые и специальные методологии, предназначенные как для контроля теплового загрязнения, так и для повышения энергоэффективности тепловых сетей и инфраструктуры населенных пунктов. Существующая система мониторинга тепловых островов не обеспечивает возможности проведения систематических проверок территорий с целью поиска тепловых аномалий, которые могут негативно влиять на экологию городской среды и здоровье населения.

Ключевые слова: городской остров тепла, микроклимат, глобальное потепление, плотность застройки, сельская местность.