Impact on climate change through world urbanization

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Abstract. This article discusses the environmental problems of our time, in connection with the increase in population and cities and the impact of global urbanization on the global climate change of the Earth and its use to reduce surface temperature by increasing the albedo reflectivity of urban surfaces. The study improved previous similar works due to the global spatial coverage of all settlements of the Earth's development and developed a comprehensive assessment of the degree of influence and detailed measurements of 15 parameters of modifications of surface albedo calculations using data developed by the Research Institute of Building Physics of the CIS and using satellite sensing Google Earth Pro, from a height of 5 km. As a result of the study, it was found that the urbanized territories of the Earth amounted to - 0.1514% of the Earth's area and the heat release from the development of the whole world will decrease by - 7.8 million MW, which will be -8.6 Gt CO2. The average value of the Earth's temperature will decrease by 0.003°C in a year and by 2100 by 0.35°C. This measure is recommended as an addition to the main approaches to solving the climate problem.
Keywords: global urbanization (Gu), climate change, albedo, area of cities

1 Introduction

With the increase in population and cities, the “natural environment” is gradually turning into an “urban environment,” (hereinafter) (Gu), further intensifying anthropogenic interference in nature, creating environmental problems of our time, including climate change. As the UN Secretary-General António Guterres noted:

“According to a September 2019 World Meteorological Organization (WMO) report, we are at least one degree Celsius above preindustrial levels and close to what scientists warn would be “an unacceptable risk”. The 2015 Paris Agreement on climate change calls for holding eventual warming “well below” two degrees Celsius, and for the pursuit of efforts

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to limit the increase even further, to 1.5 degrees. But if we don't slow global emissions, temperatures could rise to above three degrees Celsius by 2100, causing further irreversible damage to our ecosystems" [1].

This is due to greenhouse gas emissions and urban development. Dark surfaces (roofs, walls) of urban development lead to the "heat island effect", an increase in the surface temperature of cities, in the process of solar radiation on a global scale, contribute their share to climate change in general [2,3,4]. One of the ways that temperature drops in cities is in the reflection of solar radiation back into space through white roofs and walls.

The purpose of our study is to determine the scale of development of modern world Gu, to further study the features of the its role and contribution to climate change and promote problem solving through urban policy, increasing the "albedo" (reflectivity) of the surface of urbanization based to changes in the heat balance of the Earth.

2 Literature review

The first comprehensive numerical processing to predict the effects of an urban heat island was published by Leonard O. Mairup in 1969. His article examines the heat island of cities [5]. V.S. Ivashkin (2012) stated that one of the solutions to the "heat island effect" is the use of cool roofs [6]. Figure 1 shows the distribution of temperatures in cities.

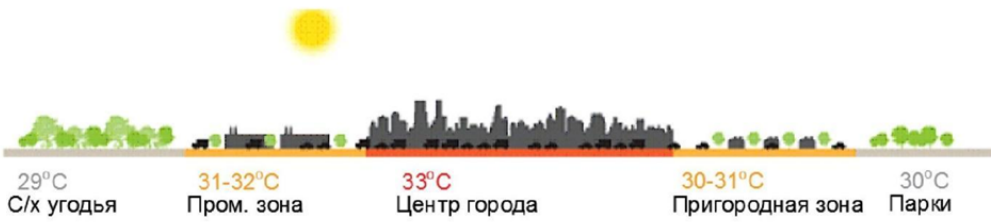
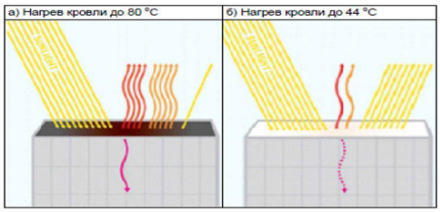


Fig. 1. Temperature distribution within a settlement [6].
Translation: Farmland - 29°C; Industrial zone - 31-32°C; City downtown - 33°C; Suburban area - 30-31°C; Parks - 30°C.



Reflective properties of the roof: traditional dark (a) and cool white roof (b), at an outdoor temperature of 37°C. Yellow - sunlight, red - heating of the atmosphere, orange - heating of urban air, purple – heating.

Fig. 2. Reflective roofs V.S. Ivashkin, A.V. Semenov, S.V. Kaloshina [6].
Translation: a) Roof's heating up to 80°C; b) Roof's heating up to 44°C.

The United in Science 2021 report, (WMO), attached a drawing of the current state of the temperature distribution around the globe, which is coordinated by the World Meteorological Organization (WMO). "Currently, the IPCC assessment reports, United in Science (2021), consider mainly three approaches to solving the problem of stabilizing temperature change:
- reduction of anthropogenic CO2 emissions.

- removal of the greenhouse gas CO2 from the atmosphere.
- compensation of the greenhouse effect by reducing the flow of solar radiation. (Solar Radiation Management)" [7].

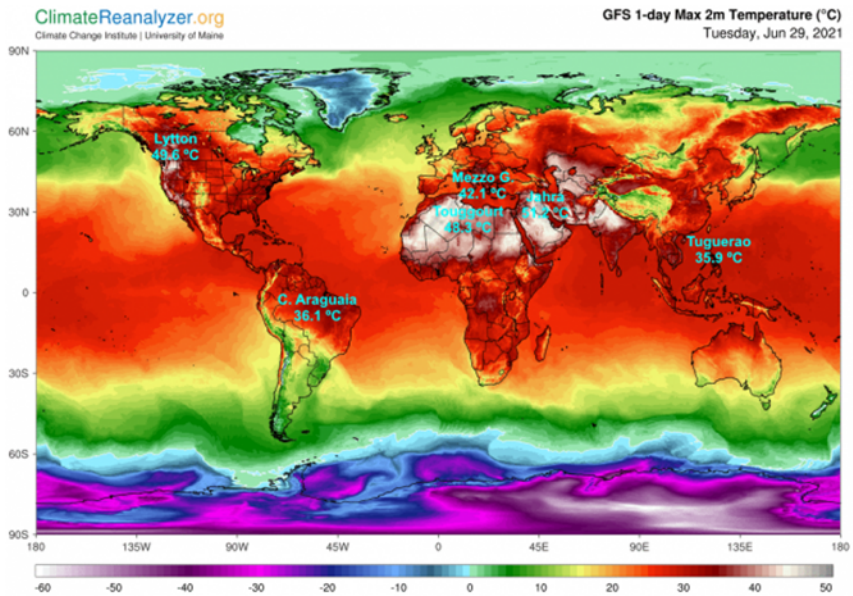


Fig. 3. Temperature distribution around the globe [7].

Extensive research is being carried out along the two main approaches and on the third approach, in the analysis of Akbari H, Matthews D, Seto D., (2012) it is said that "Solar reflective urban surfaces (white rooftops and light-colored pavements) can increase the albedo of an urban area by about 0.1. Increasing the albedo of urban and human settlement areas can in turn decrease atmospheric temperature and could potentially offset some of the anticipated temperature increase caused by global warming" [8]. According to K. W. Oleson, G. B. Bonan, and J. Feddema (2010), "Increasing roof albedo is an effective way to reduce the urban heat island. This leads to a decrease in the range of daily urban temperatures by 0.3°C" [9]. Also, Gartland (2008) argues, "Cities also suffer from an additional form of heat known as the Urban Heat Island (UHI) effect. This artificial heat is trapped in the built-in thermal mass of the environment and can result in densities much higher than those in suburban surroundings. The temperature difference between urban and rural areas often reaches 4.0°C and can reach a maximum at over 10°C" [10].

3 Methods and materials

3.1 Initial data

The initial data of the heat balance of the Earth is adopted by Trenberth (2009), see Fig. 4. According to the figure, the incoming solar radiation in the upper boundary of the earth's atmosphere, on average (Rs) 341 W/m², is weakened by various physical processes, and most of the "direct and diffuse" solar radiation reaching the underlying surface of the Earth is converted into heat.

The study used calculated data of L. T. Matveev (1984) and applied the value of the total radiation of direct and scattered fluxes of solar radiation received on the earth's surface depending on the latitude of the area, as shown in Fig.5. The values of the fluxes of the total (Q), direct (I) and scattered (i), solar radiation to a horizontal surface are given under cloudless conditions on average for the year, according to actinometrical measurements at 340 points of the globe.

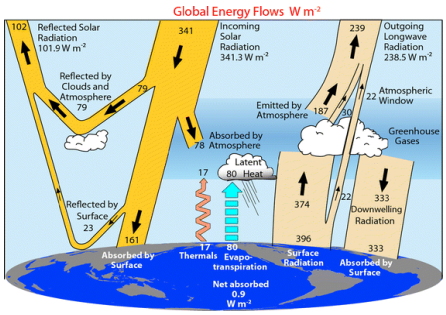


Fig. 4. The global annual mean earth's energy budget for 2000–2005 (W m–2). The broad arrows indicate the schematic flow of energy in proportion to their importance. Adapted from Trenberth et al. (2009) with changes noted in the text [11].

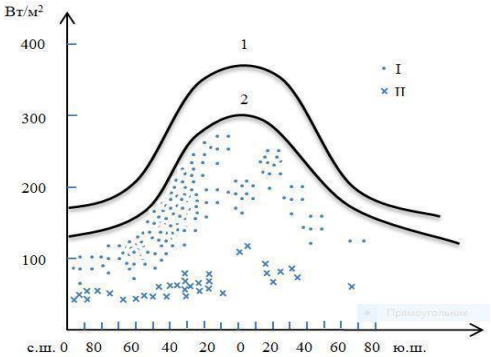


Fig. 5. Dependence on latitude on the annual average fluxes of total (I) and scattered (II) radiation. 1-the flow of solar radiation at the upper boundary of the atmosphere, 2-the flow of total radiation on the earth's surface with a cloudless sky [12].

It can be seen from the graph that the total radiation flux depends on the latitude of the area, where the maximum (Q) is observed in the equatorial region and slowly decreases to 80º northern and southern latitudes. The average range of the annual total radiation flux is about 215 W/m². "The distribution of solar radiation over the globe, the values in the northern and southern hemispheres in the corresponding latitudes are approximately the same" [12].

The value of total solar radiation (direct and diffuse) on horizontal and vertical surfaces, (kWh/m²), is shown in Tables 1 and 2, with a cloudless sky, "calculated according to the method developed in the laboratory of building climatology of the NIISF." The document was developed at the Scientific Research Institute (NII) of Building Physics by the State Committee for Hydrometeorology of the CIS, which was compiled on the basis of data from the results of long-term climatic, geophysical observations and actinometrical measurements at various points in the CIS and introduced in 01-01-2012 [13].

Table 1. Total solar radiation to a vertical surface in a cloudless sky, Wh/m² [13].

Orientation, months	Geographical latitude, degrees north latitude							
	40	44	48	52	56	60	64	68
Annual average	107	108	109	109,7	107	106,7	104,4	

Table 2. Total solar radiation to a horizontal surface with a cloudless sky, Wh/m² [13].

Months	Geographical latitude, degrees north latitude

	40	44	48	52	56	60	64	68
Annual average	171,7	161,0	152,9	143,0	131,9	121,0	115,4	129,8

Average absorption coefficient (SA - Solar Absorptance) of solar energy of roofs and walls, Table 3 is applied, Kupriyanov V.N. [14].

Table 3. Coefficient (ρ), absorption of solar radiation by various materials [14].

Material name	ρ	Material name	ρ
• Aluminium	0,5	• Tile facing blue	0,6
• Asbestos cement sheets	0,65	• White facing tiles	0,45
• Asphalt concrete	0,9	• Ruberoid with sand dressing	0,9
• Concrete	0,7	• Painted sheet steel:	
• Unpainted wood	0,6	- white paint	0,45
• Protective layer of roll roofing	0,65	- dark red	0,8
light gravel	0,65	- green paint	0,6
• Clay brick	0,7	• Galvanized roofing steel	0,65
• Silicate brick	0,6	• Facing glass	0,7
• Facing with white stone	0,45	• Plaster:	
• Coloring silicate dark grey	0,7	- limestone dark grey	0,7
• Lime white paint	0,3	- cement light blue	0,3
• Facing ceramic tiles	0,8	- cement dark green	0,6
		- cement cream	0,4

3.2 Solution methods

In order to help mitigate this problem, a concept has been developed by increasing the surface albedo (Gu), i.e. “reversing”, part of the solar radiation energy back into space. A methodology has been developed consisting of research tasks;
- comprehensive analysis of urban development and calculation of thermodynamic characteristics and collection of initial data,
- assessment of the current state and for the future; urban surfaces (Gu), albedo (SA), color of roofs and walls, solar radiation (RF), etc. on a global scale.
- development of a formula for thermodynamic calculations of buildings in a tabular form for 15 indicators in the average annual value, taking into account the average cloudiness of 20%.

3.2.1 Comprehensive assessment of the current state of radiative forcing on (Gu)

This study made a comprehensive assessment of the current state of radiation impact on (Gu) around the world and amounted to 58,800 large, small cities, towns, and 30,000 villages with an area of about 0.5 km², measured in detail along the contours of the built-up parts of cities with an error of less than 5%, in the corresponding latitude (φo) of the area, without major highways, landscaped and free areas using the Google Earth Pro satellite. Calculations are shows on global map of the Earth's urbanized territories between

2018-2021 (Fig.6.). Figure 7,8 show more detailed examples of measuring the urban areas of the Moscow region and Bishkek highlighted in red.

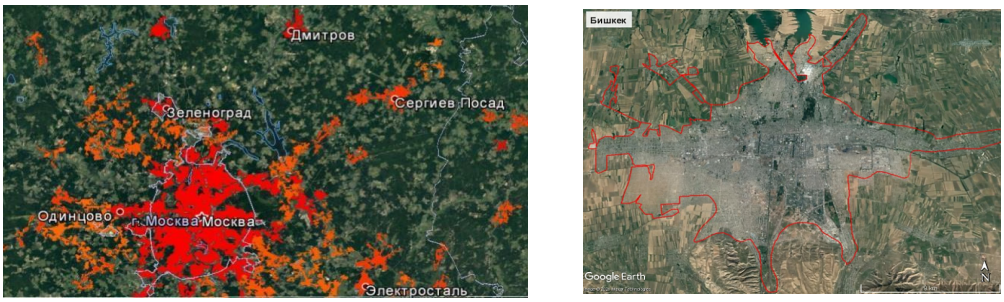


Fig. 7,8. Urbanized territories of the Moscow region and Bishkek

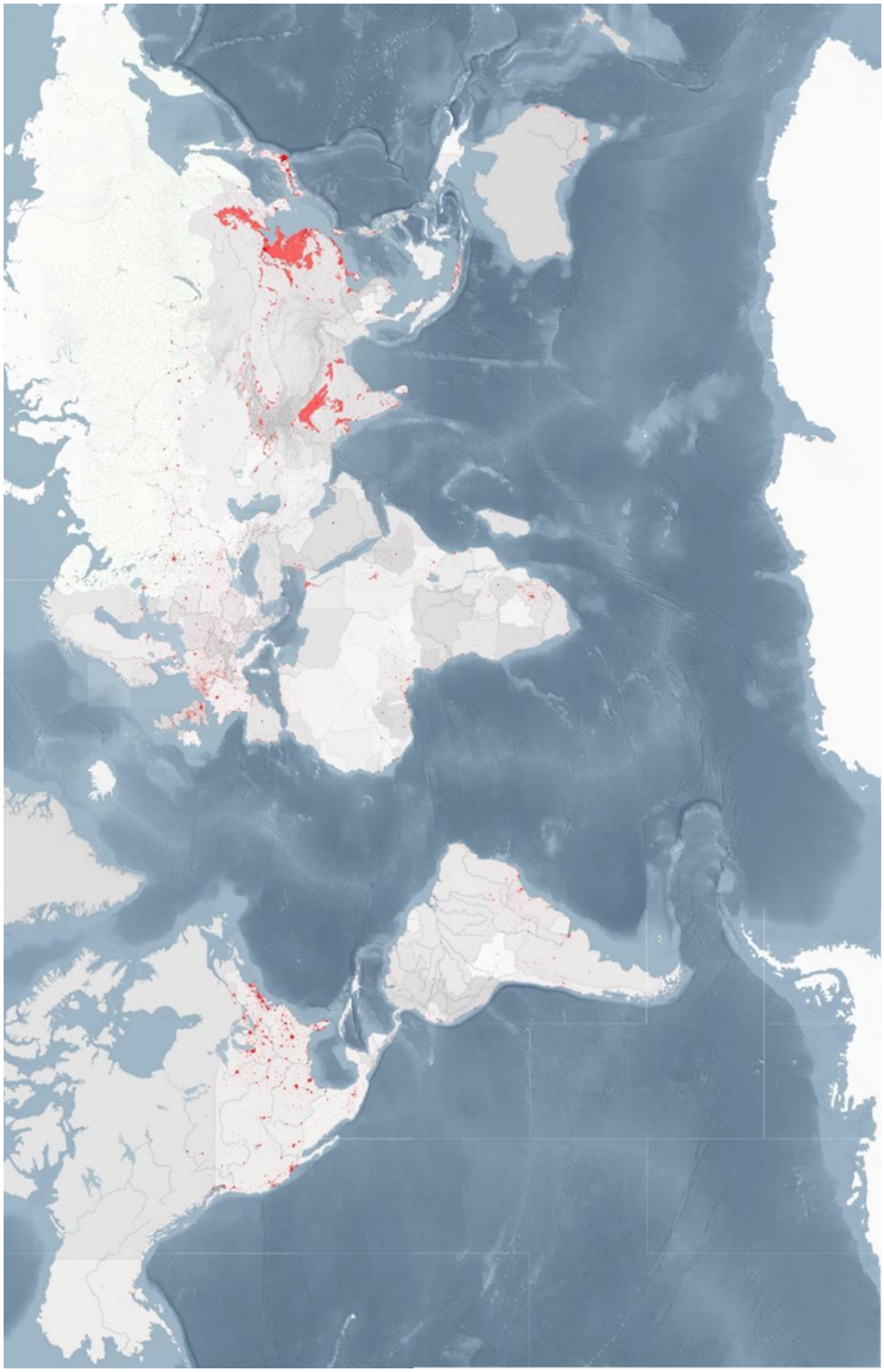


Fig.6. Global map of the Earth's urbanized territories (2018-2021). Blue - background map; red – urbanized areas. Source: Rosreestrmap.ru

Table 4. Thermodynamic calculation of the current state and perspective of urbanized environments around the world by northern and southern latitudes

№	Countries located by latitudes	S in km²	Sden sity в %	Absor ption capaci	# of floors	Amount MW horizontal	Amount MW vertical	Total number kW	Coeffi cient. Radiat	Roof area in km²	Walls area in km²	Total area in km²	Current albedo of roofs	Increase albedo of roofs	Difference of increased albedo МВт
			FAR	SA	Fl	Qh	Qv	Qhv	R	Sh	Sv	Shv	Ac	Ay	Qhw
1	Northern 68°-56°	63639,7	0,191	0,769	1,759	1592963	527142	2120105	0,9	15527,5	8443,7	23971,2	0,23	0,27	546440
2	Northern 56°-43°	55185,2	0,215	0,719	1,867	1340316	459456	1799772	1,0	14809,0	9382,3	20701,1	0,28	0,22	220334
3	Northern 43°-29°	217301,3	0,371	0,683	1,939	7799169	1936162	9735331	0,7	66038,0	34440,7	100478,7	0,32	0,18	2071145
4	Northern 29°-16°	214392,6	0,451	0,65	1,989	8665828	1901628	10455230	0,6	66808,4	27502,1	94310,5	0,35	0,15	2701522
5	Northern 16°-10°	23673,2	0,449	0,727	1,332	2139911	184819	2324730	0,6	13276,2	2696,7	15973,0	0,45	0,45	633292
6	Northern 10°-6°	47854,3	0,307	0,674	1,137	2662350	257827	2920177	0,8	17291,8	3603,7	20895,5	0,33	0,17	590579
7	Southern 6°-0°-4°	47912,8	0,344	0,698	1,258	3401389	297076	3798419	0,7	16617,7	3721,6	20339,4	0,30	0,20	1040785
8	Southern -2°-17°	8998,9	0,346	0,651	1,21	738618	54812	793430	0,7	3951,7	837,8	4789,5	0,35	0,15	198101
9	Southern -8°-27°	27705,7	0,331	0,671	1,145	2814586	169534	2984120	0,8	16587,6	2626,5	19214,1	0,33	0,17	869025
	Total	**735644,3**	**0,375**	**0,767**	**1,645**	**32742470**	**5973190**	**38703386**	**0,85**	**242934,3**	**96103,0**	**335547,1**	**0,363**	**0,237**	**9316066,0**

Note: The table indicates: the area of the city (S) km²; total solar radiation on horizontal (RFh) and vertical (RFv) surfaces in clear skies Wh/m²; latitude of the area (φo); building density (FAR) %; absorption capacity (SA)%; average number of storeys (Fl); amount of heat dissipation of roofs (Qh), walls (Qv) in kW. Radiator coefficient (R); roof surface area (Sh) km²; wall surface area (Sv) km²; total surface area (Shv) km²; existing roof albedo in (Ac)%; (Ay) roof albedo increase in %; difference in heat dissipation after white roofs (Qhw)

For a comprehensive analysis of the thermodynamic processes of urban development, formulas have been developed in a tabular form of calculation of 15 indicators, see Table 4.

4 Results

As a result of a detailed measurement of the area, (Gu) on a global scale turned out to be insignificant, the total area of cities (S) -772426.5 km², about -0.1514%, of the Earth's surface (SE) is 510098000 km², the roof surface area was (Sh) - 255081.0 km², respectively from (SE) 0.05%, For further calculations, the coefficients of the average building density (FAR) K = 0.33, and the average absorption capacity of solar radiation (SA) K = 0.69, by color, were determined, taking into account the reduction by 20%, of the average cloudiness. Based on the results of measurements and definitions, the following formulas were obtained:

1. (Sh) - roof surface area; (Sh)= S* FAR=255081 km²;
2. (Sv) - surface area of the outer walls; (Sv)= Sh/3* Fl* R=100908 km²;
3. (Shv) - total surface area of roofs and walls; (Shv)= Sh+ Shv=355989 km²;
4. (Qh) - the amount of heat dissipation of the roofs in total;
(Qh)= S * RFh* FAR*1000000/1000*SA=27503675 MW;
5. (Qv) - the amount of heat dissipation of the walls in total, in MW;
(Qv) = RFv *1000000* Sv/1000*0.55=5017479 MW;
6. (Qhv) - the total amount of flow heat dissipation of roofs and walls;
(Qhv)= Qh+ Qv=32521154MW;
7. (Ac) - existing roof albedo, coefficient (Ac)= (1-SA) =0.304;
8. (Ay) - increased roof albedo, coefficient (Ay)= SA-0.5=0.196;

9. (Qhw) - the difference in the decrease in the heat release flux after an increase in the albedo coefficient to 0.5, roofs, in MW;

(Qhw)= Qhv- ((RFh*1000000*0.5/1000* Sh)+ Qv)=7825495 MW; that the offset potential in terms of (0.91 kW/tCO2) equivalent CO2 emissions is 8.6 GtCO2.

To solve the problem, we used two methods:

Proportional calculation method. Thus, from the incoming flow of the average annual global energy (RI) of 341.3 Wm², which absorbs parts of the Earth's surface, see Fig. 4, which is (RA) 161Wm², in proportion to the roof area (SE) 0.05%, then it will turn out (161* 0.05%) =0.08 Wm², reduction (RA), this is with the existing albedo (Ac) K\u003d 0.304, if multiplied by the increased part of the albedo to (Ay)0.196, then you get a decrease in (RA) by, (0.08x 0.192) \u003d **0.04 Wm².** Consequently, the absorbing part from the Earth's surface will decrease (RA) by (161-0.04) =**160.96 kWm².** According to a similar calculation, it is possible to calculate the temperature of the Earth, if the long-term average temperature of the Earth is considered to be 15 ºC, then (15 x 0.05% x 0.5) = **0.004 ºC**, the temperature of the Earth's surface will decrease by 0.004 ºC, in one cycle.

Thermodynamic method of calculation. From the incoming flow of average annual global energy (RI) of 341.3 Wm², absorbing parts of the Earth's surface, see Figure 4, which is (RA) 161 Wm², and accordingly the Earth receives a global thermal energy (GQ) of 82125778000 MW. The difference between the existing and after increasing the roof albedo coefficient to K=0.5, the amount of heat flux was (Qhw) 7825495 MW, and has one of 10494 parts of (GQ), i.e. (82125778000/ 7825495)= 10495, if calculated proportionally, that, consider the temperature of the Earth to be 15 ºC, divide by 10495, (15/10495) = 0.00143 ºC, then it turns out that the temperature of the Earth's surface will decrease by **0.00143 ºC.**

As a result of calculations with two methods and an increase in the Earth's albedo, the average value of the Earth's temperature will decrease by an average of **0.003 ºC for 1 cycle (1 year).** In 80 years increase in temperature will be 0.24 ºC. The further development of cities increases constantly linearly, therefore, the Earth's albedo will also increase, and the temperature decreases linearly in the aggregate long-term perspective by 2100 will decrease by about **0.35 ºC.** According to the IPCC Fifth Assessment Report, see Figure 9.

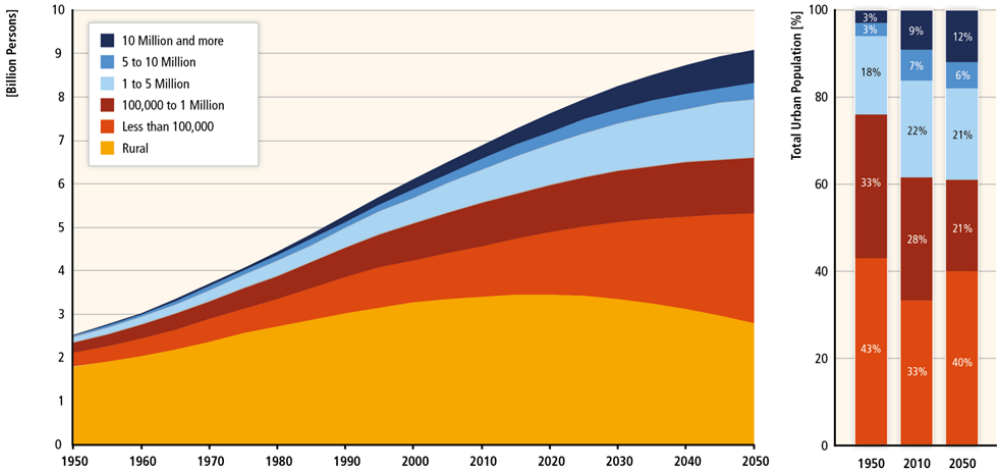


Fig. 9. Population by settlement size using historical (1950–2010) and projected data to 2050. [7]

5 Discussion

In the study, for the first time, unlike previous authors, a comprehensive analysis and assessment of thermodynamic characteristics (Gu) was carried out by an experimental method on a global scale with detailed measurements and calculations. Inaccuracies of calculations were revealed of previous authors such as H. Akbari, S. Menon, A. Rosenfeld (2008), who argued that, "Pavements and roofs typically constitute over 60% of urban surfaces (roof 20–25%, pavements about 40%). Using reflective materials, both roof and pavement albedos can be increased by about 0.25 and 0.15, respectively, resulting in a net albedo increase for urban areas of about 0.1" [15]. They calculated using up-scaling and modeling techniques, and also included roads and sidewalks. In our calculations, an increase in albedo is offered only for urban developments, buildings, without sidewalks and roads, in order to avoid light discomfort in the urban environment, the latitudes of the cities were also taken into account. From the analysis it can be seen that many developed countries have darker roofs, if all dark roofs around the world were replaced or painted white, then they could partially solve the climate problem. In addition to the increase in albedo from the surface of white roofs, the cost of air conditioning is reduced, and the efficiency is also increased, since, as can be seen from Table 4, the main part of urbanized territories is located between northern and southern latitudes within + 38º-38º.

6 Conclusions

As a result of the study, the increase in the direct reflective part of the energy back into space by increasing the albedo, (reverse), from the white roofs of world urbanization is not significant, about 0.003 ºC for 1 cycle (year), but in the long term in 80 years, it can really reduce the surface temperature by 0.35 ºC. Also, the main 15 thermodynamic and other indicators of settlements by country were found. This solution is recommended as an additional measure to the main approaches to sustainable stabilization of the Earth's temperature and needs support and assistance at the state levels; it is necessary to change the standards and norms of building standards.

References

1. United Nations. (n.d.). *The climate crisis – a race we can win*. United Nations. Retrieved March 29, 2023, from https://www.un.org/en/un75/climate-crisis-race-we-can-win
2. Ichinose, T., Matsumoto, F., & Kataoka, K. (2008). Counteracting urban heat islands in Japan. *Urban Energy Transition*, 365–380. https://doi.org/10.1016/b978-0-08-045341-5.00015-3
3. Sharifi, E., & Lehmann, S. (2015). Comparative analysis of surface urban heat island effect of rooftops and Streetscapes in central Sydney. *Journal of Urban and Environmental Engineering*, ***9*(1),** 3–11. https://doi.org/10.4090/juee.2015.v9n1.003011
4. Ashie, Y. (n.d.). Management of urban heat environment. *Urban Environmental Management and Technology*, 215–238. https://doi.org/10.1007/978-4-431-78397-8_12
5. Leonard O. Myrup. A Numerical Model of the Urban Heat Island. *Journal of Applied Meteorology*, 1969, **8,6.** doi:10.1175/1520-0450(1969)008<0908:anmotu>2.0.co;2.
6. Ivashkin, V. S., Semenov, A. V., & Kaloshina, S. V. (n.d.). Primeneniye prokhladnykh krysh [Application of cool roofs]. *Perm National Research Polytechnic University, Perm, Russian Federation*.
7. Intergovernmental Panel on Climate Change. (n.d.). *12: Human settlements, infrastructure and spatial planning*. IPCC. Retrieved March 31, 2023, from https://www.ipcc.ch/report/ar5/wg3/human-settlements-infrastructure-and-spatial-planning
8. Akbari, H., Damon Matthews, H., & Seto, D. (2012). The long-term effect of increasing the albedo of urban areas. *Environmental Research Letters*, *7***(2)**, 024004. https://doi.org/10.1088/1748-9326/7/2/024004
9. Oleson, K. W., Bonan, G. B., & Feddema, J. (2010). Effects of white roofs on urban temperature in a global climate model. *Geophysical Research Letters*, ***37*(3)**. https://doi.org/10.1029/2009gl042194
10. Gartland, L. (2008) Heat Islands Understanding and Mitigating Heat in Urban Areas in the UK and USA in 2008. Earthscan, London.
11. Trenberth, K. E., & Fasullo, J. T. (2011). Tracking Earth's Energy: From El Niño to Global Warming. *Surveys in Geophysics*, ***33*(3-4)**, 413–426. https://doi.org/10.1007/s10712-011-9150-2
12. L.T.Matveev. Kurs obshchey meteorologii Fizika atmosfery Leningrad: Gidrometeoizdat [Course of General Meteorology Atmospheric Physics Leningrad: Gidrometeoizdat], 1984.
13. Svod pravil.sp 131.13330.2012 Stroitel'naya klimatologiya. Aktualizirovannaya versiya SNiP 23-01-99*[Code of rules.sp 131.13330.2012 Building climatology. Updated version of SNiP 23-01-99*]
14. V.N. Kupriyanov. K92 Gradostroitel'naya klimatologiya: Uchebnoye posobiye/Kazan': Izd-vo Kazanskogo gosudarstvennogo arkhitekturno-stroitel'nogo universiteta [K92 Urban climatology: Textbook / Kazan: Kazan State University of Architecture and Civil Engineering] ,2012–147 c. ISBN 978–5–7829–0356–5
15. Akbari, H., Menon, S. & Rosenfeld, A. Global cooling: increasing world-wide urban albedos to offset CO2. *Climatic Change* **94**, 275–286 (2009). https://doi.org/10.1007/s10584-008-9515-9