Mitigation of earth's climate change through the reversal of solar radiation from global urbanization

Kanybek Kaepkulov[1]* , *Nargiza* Kanybek Kyzy[2], and *Benazir* Kanybek Kyzy[3]

[1] Kyrgyz State Technical University named after I. Razzakov (KSTU), Bishkek, the Kyrgyz Republic
[2] American University, Washington, D.C.
[3] Bay Atlantic University (BAU), Washington, D.C.

Abstract. This study explores the mitigation of earth's climate change through the reversal of solar radiation caused by global urbanization. The analysis incorporates thermodynamic calculations, urban climate models, and solar radiation data to examine potential solutions. Our results highlight that large-scale reflective urban designs and innovative technologies could substantially reduce heat absorption in densely populated regions, contributing to climate change mitigation. Implications for sustainable city planning and environmental policy are also discussed.

Keywords: global urbanization (Gu), climate change mitigation, albedo, sustainable cities

1 Introduction

Urbanization has become a defining feature of the 21st century, shaping both human society and the global climate system. 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 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].

The aim of this study is to assess the extent of development in the modern urban world and to examine how it contributes to climate change. It also seeks to support solutions through urban policy, particularly by increasing the reflectivity ("albedo") of urban surfaces to influence the Earth' s heat balance. Climate change is driven in part by greenhouse gas emissions and patterns of urban development. Dark surfaces (roofs, walls) of urban development led to the "heat island effect", an increase in the surface temperature of cities,

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* Corresponding author: kaepkulov.kanybek@gmail.com

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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.

2 Methods and materials

The methodology combined spatial analysis with energy balance modeling. Using Google Earth Pro satellite imagery at 5 km resolution, urbanized territories were mapped for 58,800 cities and 30,000 villages. Seventeen parameters were assessed, including surface area of roofs and walls, average building density, solar absorption coefficients, and height profiles of urban environments. The Research Institute of Building Physics (CIS) provided radiation data, while albedo values were derived from material reflectivity tables. Both proportional and thermodynamic calculation methods were applied to estimate the effect of increased albedo on radiative forcing and global mean surface temperature.

2.1 Initial data

The foundational data for Earth’s heat balance in this study is based on Trenberth (2009), as illustrated in Figure 1. The average incoming solar radiation at the top of the atmosphere (Rs) is estimated at 341 W/m^2. As this energy passes through the atmosphere, it is diminished by a range of physical processes, with a large portion of the remaining direct and diffuse radiation that reaches the Earth’s surface ultimately being transformed into thermal energy.

This analysis also incorporates computed results from L. T. Matveev (1984), using values of total solar radiation—both direct and scattered-received at the Earth’s surface as a function of latitude (see Figure 2). The reported values for total (Q), direct (I), and diffuse (i) radiation fluxes on a horizontal surface represent annual averages under clear-sky conditions. These estimates are derived from actinometric observations collected at 340 locations worldwide [5].

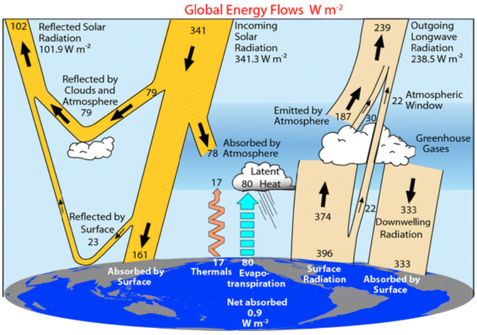

Fig. 1. The Earth’s average global energy budget for the period 2000-2005, expressed in W/m^2, is illustrated with arrows whose widths represent the relative magnitude of energy flows. This depiction is based on Trenberth et al. (2009), with modifications as described in the accompanying text [6].

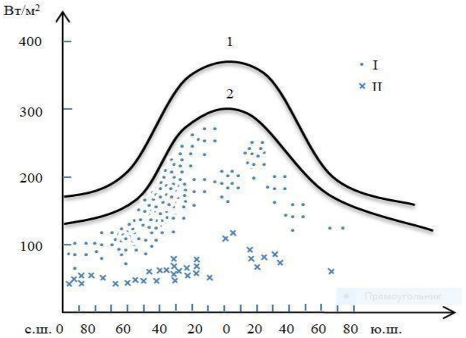

Fig. 2. Variation with latitude in the yearly average fluxes of total (I) and diffuse (II) solar radiation is illustrated. Curve 1 represents the incoming solar radiation at the top of the atmosphere, while curve 2 shows the total radiation reaching the Earth’s surface under clear-sky conditions [7].

The graph indicates that total solar radiation flux varies with latitude, reaching its highest levels in equatorial regions and gradually declining toward both the northern and southern latitudes up to about 80 degrees. The mean annual range of total radiation is approximately

215 W/m^2. Additionally, the spatial distribution of solar radiation is generally symmetrical, with similar values observed at corresponding latitudes in both hemispheres [7].

Tables 1 and 2 present the total incoming solar radiation (including both direct and diffuse components) on horizontal and vertical surfaces, expressed in kWh/m^2, under clear-sky conditions. These values were calculated using a methodology developed by the Laboratory of Building Climatology at NIISF. The underlying dataset originates from the Scientific Research Institute of Building Physics under the CIS State Committee for Hydrometeorology and is based on extensive long-term climatic and geophysical records, along with actinometric measurements collected across multiple locations in the CIS. The dataset was formally introduced on January 1, 2012 [8].

Table 1. Total solar radiation to a vertical surface in a cloudless sky, Wh/m² [8].

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 [8].

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

Table 3 presents the average solar absorptance (SA) values for roofing and wall materials, based on data reported by Kupriyanov V.N. [8].

Table 3. Coefficient (ρ), absorption of solar radiation by various materials [9].

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

Analysis revealed that urbanized territories account for 0.1514% of the Earth's surface and 0.583% of land area (excluding Antarctica and Greenland). The global albedo increased by 0.0034% as a result of urbanization. Enhancing albedo via reflective surfaces (e.g., white roofs) would reduce the heat release flux by 7.8 MMW, equivalent to 8.6 $GtCO_2$ emissions.

Thermodynamic modeling projected that global average temperature could decrease by 0.003 °C in the short term and up to 0.24 °C by 2100.

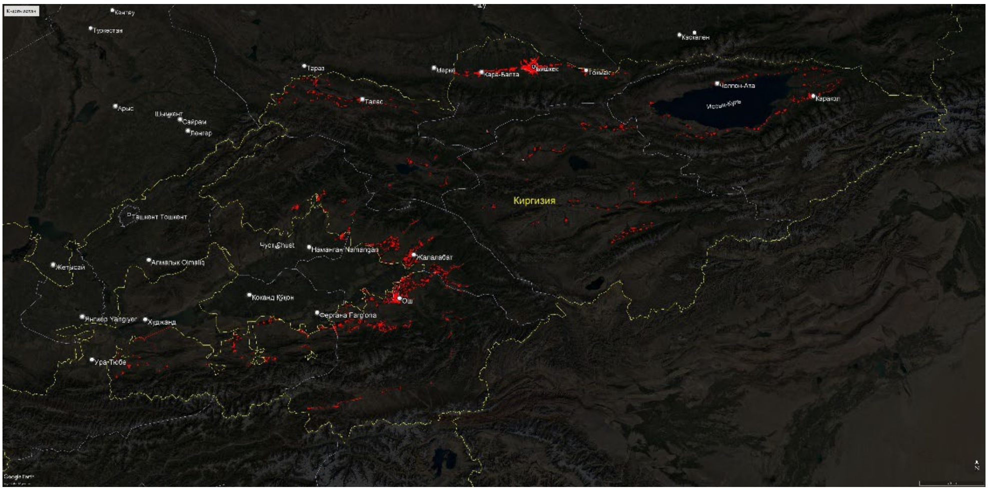

Fig.3. Urbanized territories of Kyrgyzstan

In calculations to identify real indicators of impact parameters (RF) on urban surfaces (Shv) km2 (roofs, walls) of settlements around the world, analytical calculation methods have been developed from 17 indicators. Calculation of the area of built-up parts of the territories of settlements, measured in detail along the contours of the city with an error of less than 5%, in the corresponding latitude (φo) of the area, (see tab. No. 1; 2), without major highways, landscaped and free areas using the Google Earth program Pro sounding at an altitude of about -5 km. Fig.3, Fig.4 and Fig.5 show an example of the urbanized territories of Kyrgyzstan and city of Bishkek, Kyrgyzstan, the outline of the city in red and free areas using the Google Earth program Pro sounding at an altitude of about -5 km.

Fig.4. Urbanized areas of the city of Bishkek

Fig.5. A fragment of the built-up part of Bishkek from a height of 4.6 km

The unit of measurement of the obtained area is taken in square kilometers (Km2) which is the initial data. For further calculations, the average building density (FAR) in %, and the average absorption coefficient (SA - Solar Absorptance), solar energy of roofs, determined by color and material throughout.

Next, the average number of floors (Fl), or the average height of the entire city, is determined, considering 1 floor 3 meters, using the street view functions in different parts of the city using Google Earth Pro, to further calculate the total vertical surface area of the entire city to determine the relative solar coefficient reflections (SRI - Solar Reflective Index). All visual definitions and measurements were made by interpolation close to reality. Based on the results of measurements and definitions of urban urbanizations in the interaction of physical processes with solar radiation, we obtained the following formula under cloudless conditions and consider the example of Kyrgyzstan:

Table No. 1. Shows analytical calculations of the current state of impact (RF) on urban surfaces, albedo of roof walls, heat release of roofs and walls (Qhw);

1.(Sh)-- find the surface area of roofs in km2;

$$(Sh) = S * FAR = 104.8 \text{ km2.}$$

Where S is the area of the settlement in km2; FAR - building density of the settlement;

2.(Sv)-- find the surface area of the walls in km2;

$$(Sv) = Sh/3 * Fl * R = 75.5 \text{ km2.}$$

Where Sh is the roof surface area in km2; Fl-- the average number of stores of the city; 3-- divider, relative to the area of the roof on the area of the walls for three building orientations.

3.(Shv)-- find the total surface area of roofs and walls in km2;

$$(Shv) = Sh + Shv = 161.4 \text{ km2}$$

(R)-- coefficient of radiance; “Radiator” is a correction value, building density, that is, a correction factor of which will be introduced (K) from 0.85-1.25 on the degree of fragmentation or solidity, building height (volume-spatial structure) to correct the area of city walls, (Sv) in the form of the following formula:

$$(R)=(1-FAR)*K$$

Where FAR is building density; K - correction factor;

4. (Qh)—we find the amount of heat dissipation from the roofs of the entire city in kW;

$$(Qh)= S * RFh * FAR*1000000/1000*SA= 11585640 \text{ kW}$$

Where S is the area of the settlement in km2; RFh is the average annual total solar radiation on a horizontal surface in accordance with the latitude of the city, taken from Table No. 2. Wh/m2; FAR - building density of the settlement; 1000000—conversion unit (km2) per (m2); 1000--conversion unit (W) per (kW); SA-- absorption coefficient of the roof;

5.(Qv) - we find the amount of heat dissipation of the walls of the entire city in kW;

(Qv) \u003d RFv * 1000000 * Sv / 1000 * 0.55 \u003d 4440586 kW.

Where RFv is the average annual total solar radiation on a vertical surface in accordance with the latitude of the city, taken from table No. 2. Wh / m2; 1000000—conversion unit (km2) per (m2); 1000-- conversion unit (W) per (kW);

Sv - wall surface area (km2); 0.55 - the absorption coefficient of the walls is taken as the average value of the same throughout the country;

6. (Qhv) - we find the total amount of heat dissipation of walls and roofs in kW; (Qhv)= Qh+ Qv = 16026225 kW.

7. (Ac)-- find the existing roof albedo in%; (Ac)= (1-SA)= 0.33%.

Where SA is the absorption capacity in% or coefficient;

8. (Ay) - we find the increased roof albedo in%; (Ay) \u003d SA-0.5 \u003d 0.17%.

Where SA is the absorption capacity in% or coefficient; 0.5 - absorption coefficient of roofs made of metal sheets painted with white paint selected from table No. 3.

9. (Qhw)-- we calculate the difference in the decrease in heat release after an increase in the albedo of the roofs in kW;

$$(Qhw)= Qhv- ((RFh*1000000*0.5/1000* Sh)+ Qv)= 2939640 \text{ kW};$$

Where Qhv-- The total amount of the existing heat dissipation in kW; RFh is the average annual total solar radiation on a horizontal surface in accordance with the latitude of the city, taken from Table No. 2. Wh/m2; 1000000—conversion unit (km2) per (m2); 0.5 - absorption coefficient of roofs made of metal sheets painted with white paint selected from table No. 3; 1000-- conversion unit (W) per (kW); Sh - roof surface area in km2; Qv - the amount of the existing position of the heat dissipation of the walls in kW. Fig.6 and Fig.7 show the urbanized areas of United States of America and China, respectively.

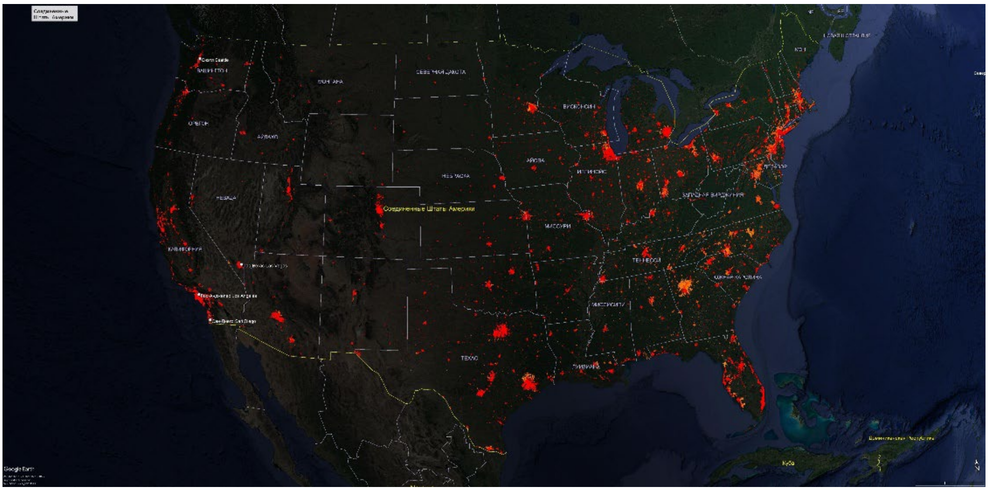

Fig.6.United States of America

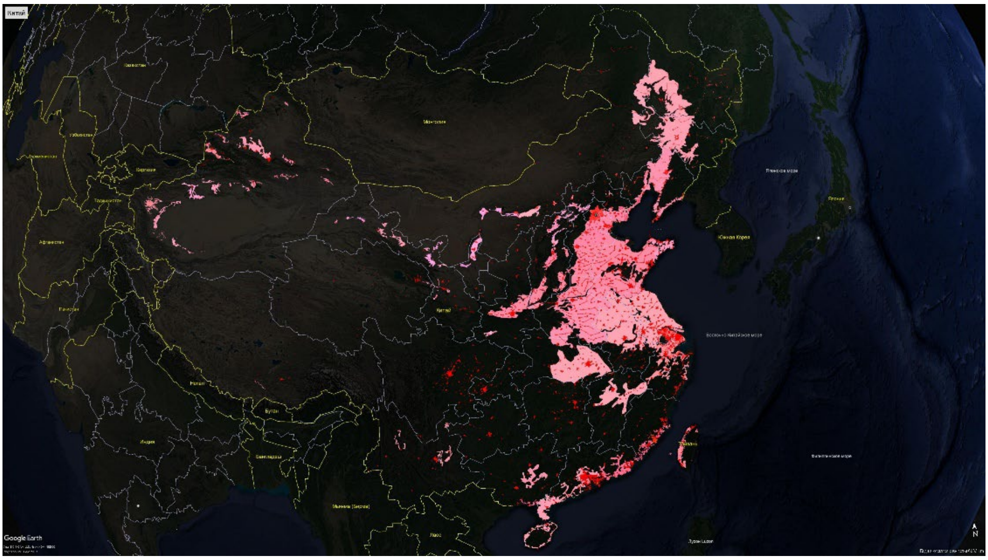

Fig.7. China

In a similar calculation, we calculated on a global scale, about 58,800 large, small cities, towns, and 30,000 villages were identified, and 4% of unaccounted small villages were included in the calculation. Please see Fig.8 for comparison for previously calculated urbanized areas.

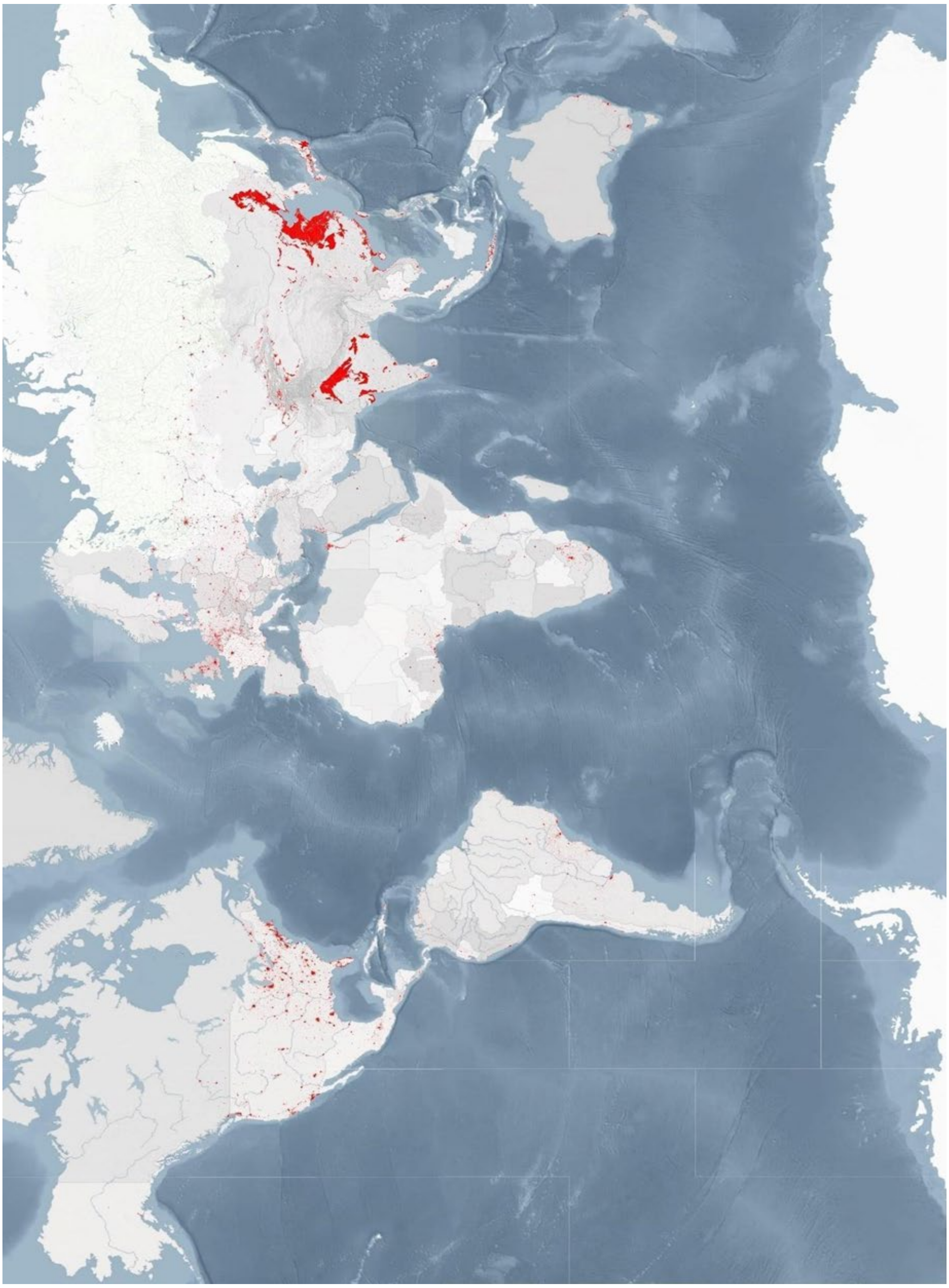

Fig.8 Global map of the Earth's urbanized territories (2018-2021). Blue - background map; red – urbanized areas. Source: Rosreestrmap.ru

In our study on the impact on Earth's climate change by the albedo of solar radiation in the direction of decreasing surface temperature, 17 parameters were used in interactions (Gu) with solar radiation, taking into account the attenuation under the influence of cloudiness by 20% L. T. Matveev (1984) [10] and the following values are revealed:

(S) - area of settlements (Gu) - 772426.5 km2;

(RFh) - the average annual total solar radiation on a horizontal surface in accordance with the latitude of cities - 204.14 W.h / m2
(RFv) - the average annual total solar radiation on a vertical surface in accordance with the latitude of cities - 107.13 Wh / m2
(FAR) - building density, excluding roads and sidewalks - 0.333%;

(SA) - average absorption coefficient (SA - Solar Absorptance) - 0.687%, after white roofs (in the future) - 0.5%.
(Fl) - the average number of storeys of settlements - 1.57 floor; (Qh) - the amount of heat release from the roofs - 27503675 MW; (Qv) - the amount of heat dissipation of the walls - 5017479 MW;
(Qhv) – total amount of heat dissipation flow of walls and roofs – 32510845 MW;

(R) - coefficient of radiance, correction value of building density - 0.76; (Sh) - roof surface area - 255081.0 km2;
(Sv) - wall surface area - 100908.1 km2;

(Shv) - total surface area of roofs and walls - 355989.1 km2; (Ac) - existing roof albedo - 0.304%;
(Ay) – increase in albedo up to 0.5%, amounted to – 0.192%;

(Qhw) - the amount of decrease in the heat release flux, the difference between the existing and after the increase in the albedo of the roofs - 7825495 MW;
Compensation potential in terms of (0.91 kW / t CO2) CO2 equivalent, is -8.6 Gt CO2
Analytical calculations of world urbanization, current state and in the future, impact (RF) on the urban surface and increase in roof albedo in%.

The table provides the following parameters: city area (S) in km²; total solar radiation on horizontal (RF_h) and vertical (RF_v) surfaces under clear-sky conditions in Wh/m²; geographic latitude (ϕ°); building density expressed as FAR (%); solar absorptance (SA, %); average building height in number of floors (Fl); heat release from roofs (Qh) and walls (Qv) in kW; radiator coefficient (R); roof surface area (Sh) in km²; wall surface area (Sv) in km²; combined surface area (Shv) in km²; current roof albedo (Ac, %); increase in roof albedo (Ay, %); and the resulting change in heat dissipation after applying reflective (white) roofs (Qhw).

To solve the problem, we used two methods:

Proportional calculation method. Starting with the average annual incoming global energy (RI) of 341.3 W/m², the portion absorbed by the Earth's surface (RA) is taken as 161 W/m² (see Fig. 4). Considering that roofs account for 0.05% of the surface area, their share of absorbed energy is estimated as 161 × 0.05% = 0.08 W/m². This value corresponds to the current albedo (Ac = 0.304). When factoring in an albedo increase of 0.196 (Ay), the reduction in absorbed energy becomes 0.08 × 0.192 ≈ 0.04 W/m². As a result, the total absorbed energy at the Earth's surface decreases slightly to 160.96 W/m².

Using a comparable proportional method, the impact on temperature can also be estimated. Assuming a long-term global average temperature of 15° C, the reduction is calculated as 15 × 0.05% × 0.5, which equals approximately 0.004° C. This suggests a small decrease in surface temperature per cycle [5].

Thermodynamic method of calculation. According to Trenberth (2009) “Received flow of the average annual global energy budget of the Earth for 2000–2005.” the absorbing part of the Earth's surface is (RA) -161 Wm2, and accordingly the Earth receives global thermal energy (GQ) - 82125778000 MW. According to the thermodynamic method of calculation, the total amount of the heat release flow of walls and roofs - (Qhv) - 32521154 MW, the amount of heat release from the roofs (Qh) - 27503675 MW, and the amount of heat release flow of the walls of which was (Qv) - 5017479 MW, were not taken into account.

Since the existing albedo is close to -0.5%. The difference between the existing roof albedo and after increasing it to -0.5% was (Qhw) - 7825495 MW, and has one of 10494 parts from (GQ), that is, (82125778000 / 7825495) = 10495., if we calculate proportionally that, temperature For the Earth, consider 15 Co, multiply by -10495, (15 / 10495) = 0.00143 Co. Then it turns out that the temperature of the Earth's surface will decrease by -0.00143 Co [5].

According to Trenberth (2009) [6] from the total radiation balance of the Earth -341.3 W m2, the existing albedo (reflected part of the energy) from n the city, was visually determined to determine the amount of heat released (Qh). See table No. 1 Kupriyanov V.N. (2012) [9]. 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 $^{\mathrm{O}}$C. According to the IPCC Fifth Assessment Report, see Fig. 9.

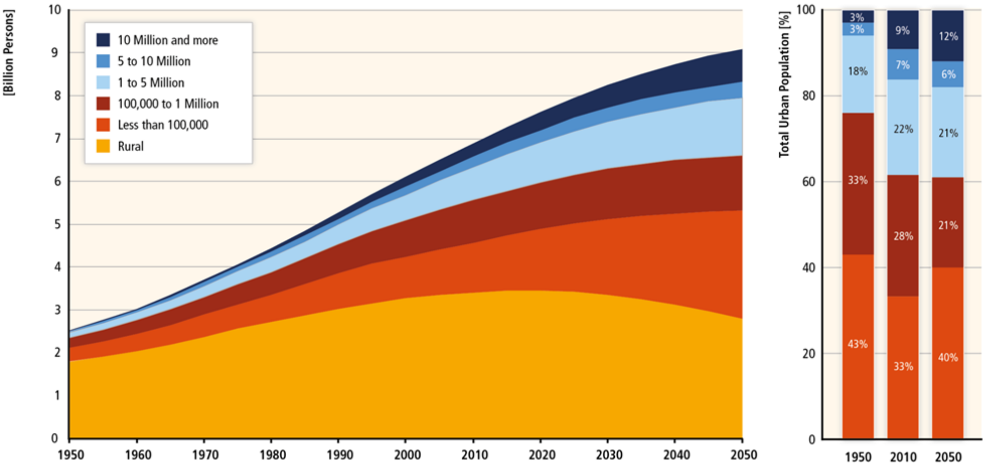

Fig. 9. Population by settlement size using historical (1950–2010) and projected data to 2050. [11]

3 Findings

Mitigation of Earth's climate change based on increasing the direct reflective part of the energy back into space "reverse", by increasing the albedo from the surface of the white roofs of the world's urbanization, can indeed reduce the surface temperature by about -0.24 C, by 2100. In our study, for the first time, the areas were measured in detail and the properties of solar radiation in the urbanized environments of each state and settlements were comprehensively assessed. In total, 58,800 large, small cities, towns, as well as 30,000 villages and small villages around the world are covered - about - 5%, unaccounted for small villages - about- 4%, sounding at an altitude of about -5 km, using the Google Earth Pro satellite map program. The study used statistical data from the Scientific Research Institute of Building Physics of the State Committee for Hydrometeorology of the CIS, introduced in 2012, developed according to the methodology of laboratory studies of actual measurements of direct and diffuse radiation, based on data from the results of long-term climatic, geophysical observations and actinometric measurements at various points in the CIS, taking into account latitude of settlements. As a result of the study, the main indicators were found in 17 points and shown in the previous chapter. The calculation takes into account - 20% weakening of solar radiation under the influence of cloudiness. Increases in albedo from the surface of white roofs reduce the cost of air conditioning very effectively, since Table No. 5 shows that the majority of urban areas are located between latitudes 38o-0o. The analysis shows that many developed countries have darker roofs. The use of white roofs in all countries at the national legislative level would serve as an impetus for a partial solution to climate problems. To support and facilitate the implementation of such a process, it is necessary to strengthen the political will in states.

The final calculations show that the share of solar radiation reflected back into space from world urbanization is not significant, but in the long term it can contribute with other methods to stable stabilization of the Earth's temperature.

4 Discussion and Implications

The results indicate that while the immediate cooling potential of albedo enhancement is modest, its long-term effect is non-negligible when combined with other mitigation measures. The global assessment underscores the policy relevance of implementing reflective urban materials, particularly in rapidly urbanizing regions. Wider adoption of cool roof and wall technologies could reduce reliance on energy-intensive cooling systems and contribute to international climate goals.

5 Conclusions

Mitigation of Earth’s climate change through the reverse of solar radiation from urbanized territories is both feasible and impactful. By systematically increasing urban albedo, surface temperatures could be lowered by up to 0.24 °C by 2100. Although not a standalone solution, it represents an important complementary strategy to carbon reduction policies and renewable energy transitions. Future research should explore implementation pathways, cost-effectiveness, and socio-political barriers to adoption.

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