Chameleon city: thermochromic urban floor

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Abstract
The rapid rise in global temperatures due to climate change has led to increasingly sweltering summers in many cities worldwide. As a result, the urban population is facing unbearable heat waves, exacerbated by the urban heat island effect and lack of green spaces. Prolonged exposure to high temperatures can lead to heat-related illnesses, dehydration, and even mortality, particularly among vulnerable groups such as the elderly, young children, and those with pre-existing medical conditions. In order to improve the temperature peak during summer time in the urban environment we need to take measures at a greater scale than before, making changes at city level. The biggest surface of the city is the ground surface itself, covered in great proportion with asphalt and concrete that are absorbing the heat from solar radiation, increasing the ground level temperature above the comfort levels, often higher than 60°C. As we know, white-colored surfaces can reflect a significant amount of light and heat back into the environment, keeping the surrounding environment cooler. In contrast, darker colors tend to absorb more light and heat, causing them to warm up more quickly and emit less reflected radiation. Taking all this into consideration, I am proposing a solution that can reduce the ground level temperature during summertime and increase the temperature during the cooler season: the use of a new upper layer material for the surfaces of streets, walkways and squares in all urban exterior environment as a technique of passive energy retrofit. Such a material is an asphalt mixed with a dark thermochromic pigment that changes colour depending on temperature. Few °C degrees under activation temperature pigment colour starts to fade and when temperature reaches 30°C the pigment becomes fully white.This bold, ambitious and forward-looking concept could reimagine the way future generations live in the city environment in the context of climate change and severe weather conditions.

Keywords: environment, climate change, global warming, extreme temperatures, climate action.

1. Introduction: climate change impact on the urban environment

Personal safety is a very important urban issue. Danger is usually considered to be caused by poverty and social disparities. However, other physical forces can also encourage aggression. It has already been observed and demonstrated that high temperatures in urban environments, above 29 degrees Celsius, increase the risk of violence [1]. Some study results indicate that increases in daily mean or maximum temperature are associated with higher incidences of violent crimes, which accounts for the near immediate reactions or actions from the preceding day temperatures [2].

A global study estimated that each 1°C increase in annual temperature is associated with an average 6% rise in homicide rates [3]. As global temperatures rise and heat waves become more severe [4], understanding and addressing the complex interplay between environmental stressors such as extreme heat events and social inequities will be critical for building resilience and ensuring equitable outcomes [5].

In recent decades, heat has become the leading cause of death from extreme weather events in Europe. The figures are dramatic: approximately 61,700 deaths associated with high temperatures in 2022 and 47,700 in 2023.

Romania is part of this worrying statistic with 2,585 deaths in 2022 and 2,500 deaths in 2023. Heat-related mortality in Romania increased by almost 8% between 2013 and 2022 compared to the period 2003-2012.

By 2040, 50% of Romania's urban population will be affected by extreme heat waves. The seriousness of the situation is also demonstrated by the very high number of calls to the 112 emergency number during heat waves. Thus, in just 48 hours (July 26–28, 2025), in the context of an extreme heat wave (red alert) and other severe weather phenomena, the Special Telecommunications Service recorded a record of nearly 57,700 calls to 112. Most of these were on Sunday, July 27, with an average of five calls per minute, including over 5,500 calls related to respiratory problems, people collapsing in public spaces, and heatwave-related emergencies. This episode is not an isolated incident; it is part of a broader, concerning picture that is already recognized worldwide [6].

Current scientific evidence unequivocally shows that heat stress has a direct and profound impact on our physical and mental health. We are no longer talking about hypotheses or statistical coincidences, but about well-documented pathophysiological mechanisms through which high temperatures affect the cardiovascular, respiratory, central nervous systems, and even the skin—the body's largest organ [7].

Prolonged exposure to high temperatures can also lead to heat-related illnesses, dehydration, and even mortality, particularly among vulnerable groups such as the elderly, young children, and those with pre-existing medical conditions.

We can conclude that shifting the temperature of urban spaces to a more comfortable range can promote prosocial behavior and help reduce crime.

2. Climate change mitigation policies

Regarding the climate change phenomenon, a multitude of climate-mitigating policies have been formulated worldwide. These policies continue to be the focus of continuous efforts to improve regulations, production methods, consumer behaviour, innovation, and technology.

The European Green Deal emphasizes the importance of sustainable resource consumption and advocates for investment in the development of green skills and technologies.

Focusing on eight key policy areas (biodiversity, sustainable food systems, sustainable agriculture, clean energy, sustainable industry, building and renovating, sustainable mobility, eliminating pollution and climate action), the European Green Deal seeks to achieve its objectives by integrating environmental protection, sustainability, and climate change initiatives into all EU programs and policies.

On the list of initiatives carried out by the consulted Creative Europe Desks to raise awareness and disseminate information about green objectives, practices, and tools, we can also find initiatives from the Romanian Creative Europe Desk, such as to collect good practices to develop guidance on the sustainability of open-air museums, campaigns on bicycles, and other creative solutions.

Among the sector-specific opportunities for Creative Europe Programme to enhance the CCS sustainability and contribution to the Green Deal objectives (such as Greening efforts for architecture) we can find the collaboration and consulting with architects and urban designers who have a holistic view, combining user, culture and environmental as well as engineering perspectives [8].

This paper formulates a innovative approach in the way we can make a technological intervention that can bring measurable results in the urban environment comfort and general well being.

3. Current situation

Trends in global temperature are an important indicator of the magnitude of climate change and its potential impacts. Global annual near-surface temperatures, measured at approximately 2 meters above the ground, have been steadily increasing since the end of the 19th century. The rate of increase has been particularly high since the 1970s at about 0.2°C per decade. During this period, the global temperature has risen more rapidly than in any other 50-year span over the past 2,000 years. The last decade (2015-2024) has recorded the highest temperatures ever observed [9].

All temperature datasets used here place the year 2024 as the warmest on record, with anomaly ranges between 1.51°C and 1.60°C above pre-industrial levels [10].

Global mean temperature between 2015 and 2024 was 1.24 to 1.28°C warmer than the pre-industrial level, which makes it the warmest decade on record. European land temperatures have increased even faster over the same period by 2.19 to 2.26°C, depending on the dataset used. The member countries of the United Nations Framework Convention on Climate Change have committed to limiting the global temperature increase to well below 2°C above pre-industrial levels, with an aim to restrict the increase to 1.5°C. Without drastic cuts in global greenhouse gas emissions, the 2°C limit is likely to be exceeded before 2050 [11].

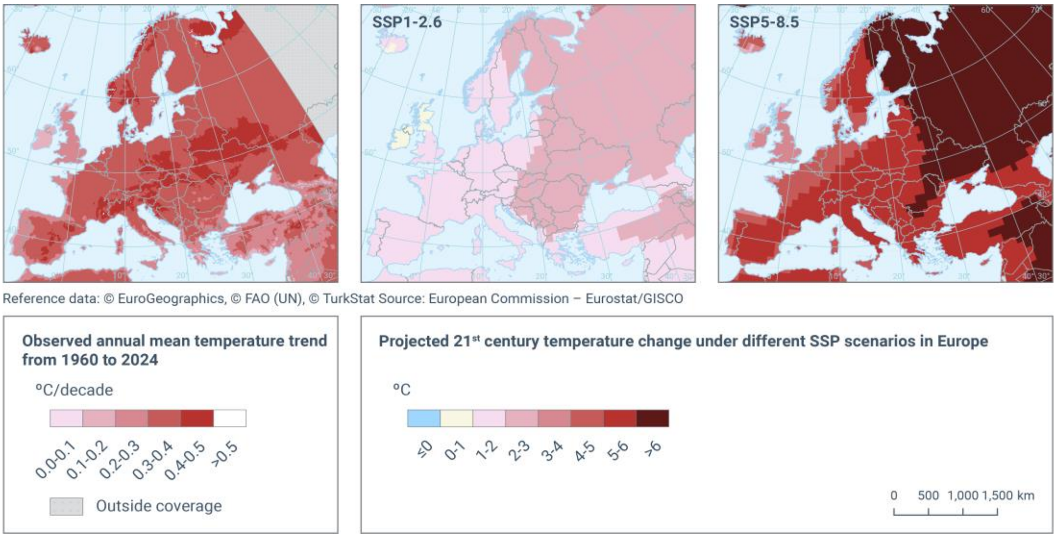

Fig. 1. Observed annual mean temperature trend from 1960 to 2024 (left panel) and projected 21st century temperature change under different SSP scenarios (right panels) in Europe.
Left panel: Temperature trend from reanalysis dataset ERA5-Land produced by European Centre of Medium-Range Weather Forecasts (ECMWF); Right panel: Projected temperature change between the WMO reference period 1981-2010 and the end of the 21st century (period 2081-2100) under the scenario SSP1-2.6, and projected temperature change between the WMO reference period 1981-2010 and the end of the 21st century (period 2081-2100) under the scenario SSP5-8.5.
Source: European Environment Agency

The EU Mission on Adaptation to Climate Change, launched in 2021, accelerates the deployment of solutions to enhance climate resilience. It supports regions, cities, and local authorities in preparing for risks like heatwaves, floods, and droughts.

Paolo Ferrecchi, General Manager of the General Directorate for Land and Environmental Care of Emilia-Romagna Region has recently addressed this issue :

“Public investment is better and much more efficiently spent in prevention rather than in repairing damages caused by climate change, when observing the medium-long term perspective. … There is a need for a paradigm shift, and the attention on adaptation will be beneficial to address such kind of investment needs at the EU level [12].”

4. Thermocromic pavement and asphalt: a viable solution

In order to improve the temperature peak during summer time in the urban environment we need to take measures at a greater scale than before, making changes at city level.

One of the biggest surfaces of the city is of course the ground surface itself, covered in great proportion with asphalt and concrete that are absorbing the heat from the increased solar radiation and create a ground level temperature above the comfort levels, often higher than 60°C.

As we know, white-colored surfaces have a high albedo, which means they reflect a significant amount of light and heat back into the environment. This is because white surfaces are typically made up of tiny particles or molecules that scatter shorter wavelengths of light, such as blue and violet, in all directions. As a result, white surfaces tend to reflect more sunlight and heat radiation, which can help keep the surrounding environment cooler. In contrast, darker colors tend to absorb more light and heat, causing them to warm up more quickly and emit less reflected radiation.

Fig. 2. Thermocromic pavement and asphalt on Calea Victoriei Street (and sidewalk). Bucharest
Left: actual photo
Right: simulated image of the pavement color shift during the summer (exposed to high temperature)
Source: Monica-Mihaela Frangulea

Taking all this into consideration, I am proposing a solution that can reduce the ground level temperature during summertime and increase the temperature during the cooler season: the use of a new upper layer material for the surfaces of streets, walkways and squares in all urban exterior environment as a technique of passive energy retrofit.

Such a material is an asphalt mixed with a dark thermochromic pigment that changes colour depending on the current temperature. Few °C degrees under activation temperature pigment colour starts to fade and when temperature reaches the exact point pigment becomes fully white (depending on how thick pigment layer is). This process can be repeated thousands of times.

This product can be mixed with various materials such as resins, plastics, lacquers, printing inks, paints (both solvent and water-based), rubber and many others, so it can be easily mixed with a properly formulated asphalt to best accommodate the pigment without losing its strength and resistance properties.

There are already studies about how thermochromic materials, in the form of coatings, can be applied in buildings and this solution is already applicated and tested. But the use of this material on any building will imply of course the alteration of the exterior building image (as it changes color) and this effect has to be used with great care as a respect for the architectural heritage.

Considering the fact that a white surface typically reflects around 80-90% of the incident light, which means it absorbs only 10-20% of the light and it can also reflect a significant amount of heat radiation (studies suggesting that it can reflect up to 70-80% of incident infrared radiation), we realize the huge potential of this innovative concept that could reimagine the way future generations live in the city environment in the context of climate change and severe weather conditions that are disrupting more and more areas and populations around the world.

4.1. Thermocromism and thermocromic materials

Thermochromism is the property of substances to change color due to a change in temperature.

Thermochromic materials are already produced and used at industrial scale in commercial consumer products such as the mood rings or baby bottles that change to a different color when cool enough to drink, or kettles that change color when water is at 100°C or near boiling point. [13]

Organic thermocromic materials:

- Thermochromatic liquid crystals;
- Leuco dyes;
- Thermochromic papers used for thermal printers;
- Polymers (thermoplastics, duroplastics, gels or any kind of coatings);
- Inks / dyes;

Inorganic thermocromic substances:

- Cuprous mercury iodide ($Cu_2[HgI_4]$) ;
- Silver mercury iodide ($Ag_2[HgI_4]$);
- Mercury iodide ;
- a.o.

4.2. Thermochromatic polymers (organic materials)

Thermochromism can appear in thermoplastics, duroplastics, gels or any kind of coatings. The polymer itself, an embedded thermochromic additive or a high ordered structure built by the interaction of the polymer with an incorporated non-thermochromic additive can be the origin of the thermochromic effect. Furthermore, from the physical point of view, the origin of the thermochromic effect can be multifarious. So it can come from changes of light reflection, absorption and/or scattering properties with temperature [14]. The application of thermochromic polymers for adaptive solar protection is of great interest [15]. For instance, polymer films with tunable thermochromic nanoparticles, reflective or transparent to sunlight depending on the temperature, have been used to create windows that optimize to the weather [16].

A function by design strategy [17], e.g. applied for the development of non-toxic thermochromic polymers has come into the focus in the last decade [18].

Therefore, the thermochromatic polymers are the most appropriate materials for embedding in asphalt and pavement composition for the urban floor surface.

5. Other applications of thermochromatic polymers in the construction industry and architecture

Analysing the actual status of development in adaptive solar control by use of thermotropic and organic thermochromic materials, we will find out that such materials are suitable and already used for various other application such as smart windows and thermochromatic paints for buildings exterior surface [19].

5.1. Thermochromatic smart windows

Chromogenic materials are perfectly suited for application in solar control glazing (smart windows) [20]; [21]; [22]. The motivation for scientists and engineers to develop novel electrochromic, thermochromic and thermotropic materials is their great potential technical application. Usually, conventional non-switchable sun protection films work by combining the reflection and absorption of solar infrared and UV radiation, resulting in a significant decrease in heat during the summer months [23]. In contrast, thermochromic and thermotropic systems can be compared regarding their influence on the energy efficiency of the buildings. Here, the thermotropic materials, acting on the basis of reflective effects, seem to be more advantageous.

IR Dynamics and Sandia National Laboratories entered into a research partnership with the goal of designing a new material whose ability to reflect IR radiation could change based on ambient temperatures. Such a material could be used to vastly improve the efficiency of windows by allowing them to let heat in during colder months and keep it out in the warmer months, reducing the amount of energy required to regulate temperatures inside buildings, cars, and other interior spaces.

One of the leaders in the industry that produces windows that "Optimizes to the Weather" is American Elements, that are stating: "*We are in full compliance with the requirements of the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) to assure uninterrupted service of our products to our customers within the European Union/European Economic Area.*" [24].

The Innovation:The researchers turned to American Elements engineers for their expertise in the characterization and synthesis of novel advanced materials. Together, they discovered that thermochromic nanoparticles could be used to impart the desired optical properties to achieve their goals. American Elements engineers produced a number of custom-manufactured organometallic solutions to be used as precursor materials in the production of the nanoparticles.

The Result:The researchers successfully achieved their goals, producing easy-to-apply polymer films with tunable thermochromic nanoparticles that are reflective or transparent to sunlight, depending on the temperature.

5.2. Thermochromatic paints for buildings exterior surface

Thermochromic materials, in the form of coatings, can be applied in buildings as a technique of passive energy retrofit. Thermochromic coatings are characterized as active, dynamic and adaptive materials that can adjust their optical properties according to external stimuli, usually temperature. Thermochromic coating modulate their reflectance as a function of their temperature, making them an appropriate solution for combating cooling loads, without diminishing the building's thermal performance during the winter period [25].

Thermochromic materials are categorized into two subgroups, dye-based and non-dye-based thermochromic materials [26]. However, the only class of dye-based thermochromic materials that are widely, commercially available [27] and have been applicated and tested into buildings, are the leuco dyes [28].

An important yearly thermal analysis is conducted in Greece with DesignBuilder software for the cities of Athens and Thessaloniki. This study investigates the effect of thermochromic dye-based roof coatings on a residential building's thermal loads according to climatic conditions and the thermal properties of the roof. The important innovation of this study is that the colour transition procedure of the coatings is dynamically simulated as a linear function of the external surface temperature of the building's roof through a developed script, leading to accurate results. The five examined thermochromic coatings are characterized by the same low (0.42) and high (0.72) reflectivity index, the same temperature transition range (4°C), but different mean transition temperatures (26°C, 28°C, 30°C, 32°C and 34°C). These thermochromic coatings are systematically tested for a wide range of U-values (0.2–3.0 W/m2K) and the results for Athens indicate a decrease in the building's yearly electricity consumption between 2.19% and 17.13%, whereas for Thessaloniki between 0.02% and 7.72%.

The study validates the methodology and confirms that the benefits of the external application of thermochromatic paints are maximized for cities with greater cooling needs [25].

Another study by Berardi et al. [29] evaluated thermochromic paints for façades and roofs in Toronto, Canada. Four cool coatings, developed by two companies Kool Seal and Lanco, were selected and evaluated. The coatings were applied to brick squared samples (5x5 cm) in two layers. The results of this study showed an 8.9% reduction in cooling demand and a limited heating penalty of 1.7%, compared to 2.6% for cool paints. In future climate scenarios with increased cooling demand, thermochromic paints were found to reduce energy consumption by 1.3–1.5%.

Yuxuan et al. [30] investigated also the thermochromic coatings properties and found out that they reduced energy use by up to 5.02 kWh/msq compared to conventional coatings and 1.47 kWh/msq compared to cool coatings. Simulations showed they kept surfaces cooler in summer and warmer in winter, with the greatest benefits in regions with hot summers and cold winters.

6. The UV reflection and the visual impact of the thermocromic pavement on the cityscape

As we previously mentioned, one of the largest surfaces in the city is the ground itself, which is predominantly covered with asphalt and concrete. To effectively address the temperature peaks during summer in urban environments, we must implement measures on a larger scale than previously attempted and make changes at the city level.

In order to attain a permanent human settlement, the natural environment it's being transformed and shaped by cities, using physical elements. Extensive and invasive infrastructures and buildings are the main reasons through which conversion is obtained and conclude a significant impact on the environment [31].

Fig. 3. Thermocromic pavement and asphalt on Doamnei Street (and sidewalk). Bucharest (Romania)
Left: actual photo
Right: simulated image of the pavement color shift during the summer (exposed to high temperature)
Source: Monica-Mihaela Frangulea

The ground surface of the city is generally neutral from an aesthetic perspective, and any colour changes would not significantly impact the perception of the city's architecture, much like the color variations caused by rain (darker pavement) or snow (white pavement).

Visually, people are familiar with white horizontal urban surfaces in winter when they are covered with snow (sidewalks, alleys, roadways), as they are also familiar with the darker gray or even black shade when the pavement is wet from the rain.

However, there are two major issues that need to be considered: maintaining the visibility of road markings and avoiding harmful phenomena caused by UV radiation reflection.

The traffic markings on the streets (as pedestrian crossing lanes, intersection crossing markings, a.s.o.) are usually white or yellow, which can make them invisible or hard to see when the background colour of the pavement or roadway is white. This problem can be solved by changing the colour of these markings to a more intense colour, such as green, blue, red, purple, etc. The colour of the markings must also take into account the change in color of the new pavement at low temperatures (when the asphalt turns dark gray).

Fig. 4. Thermocromic pavement and asphalt on Calea Victoriei Street (and sidewalk). Bucharest (Romania)
Left: actual photo
Right: simulated image of the pavement color shift during the summer (exposed to high temperature)
Source: Monica-Mihaela Frangulea

Concerning the reflection of UV radiation in summer, a wider range of measures needs to be considered.

More than 80 to 90 percent of the sunlight falling on fresh snow is reflected back into space, compared to 15 to 35 percent of the sunlight reflected by most ice [32].

This intense reflection can damage the cornea, causing symptoms like pain, blurry vision, sensitivity to light, and redness.

In any season, sun exposure may increase the risk for conditions like: cataracts; growths on the eye (including cancer); photokeratitis (including snow blindness).

The damage to the front surface of the eye that causes snow blindness is unique because it can happen quickly. All these conditions may be prevented simply by wearing sunglasses or goggles with UV protection [33].

To mitigate these risks, a UV filter layer should be installed over the thermochromic urban flooring. Additionally, the public must be informed about the dangers of UV exposure and encouraged to use sunscreen, wear sunglasses, or sun protective clothing.

Fig. 5. Thermocromic pavement and asphalt on a street in Rome (Italy).
Left: actual photo
Right: simulated image of the pavement color shift during the summer (exposed to high temperature)
Source: Robert Roman

Once again we can conclude that the idea of replacing urban floor circulation areas (and not only) with thermochromic pavement and asphalt is bold, ambitious, and forward-looking. This concept has the potential to transform how future generations experience city life, especially in the face of climate change and extreme weather conditions.

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