



A Scenario-Based Electro-Physical Assessment of Urban Surface Heat Transfer and Electrical Cooling Demand in Smart Urban Environments

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ABSTRACT: Urban overheating is an electro-physical problem because surface heat accumulation changes outdoor temperature conditions and increases the electrical energy required for cooling. This study develops a scenario-based electro-physical assessment model for analysing the relationship between urban surface heat transfer, surface material properties, green infrastructure and electrical cooling demand. The model links physical parameters such as albedo, emissivity, thermal mass, vegetation coverage and urban–rural temperature difference with engineering indicators such as cooling energy demand, energy-efficiency improvement and CO₂ emissions related to electricity use. The case-study application uses Sofia Municipality as a spatial reference environment. Real spatial and land-use indicators are combined with scenario-based calculations in order to compare a baseline urban condition with an optimized scenario. The results are interpreted as early-stage engineering estimates rather than direct measurements of Urban Heat Island reduction or electricity consumption. The contribution of the paper is an integrated framework that connects heat-transfer processes with electrical energy performance in smart urban environments.

KEYWORDS: Electrical cooling demand, electro-physical modelling, energy efficiency, smart urban systems, Urban Heat Island.

INTRODUCTION

Urban areas change the natural energy balance of the local environment. Vegetated and permeable surfaces are often replaced by asphalt, concrete, roofs, facades and other artificial materials. These surfaces absorb solar radiation during the day, store part of the heat and release it back to the urban atmosphere later. The phenomenon is widely known as the Urban Heat Island effect. The Urban Heat Island effect has a direct engineering consequence. When outdoor temperatures rise, buildings require more cooling. This increases electrical energy consumption, especially during warm periods and heat waves. Building operation remains a major energy issue, as buildings account for a large share of global final energy consumption and energy-related emissions (IEA, 2023). Santamouris (2020) describes urban overheating as a complex problem that affects cooling energy use, peak electricity demand, thermal comfort, air quality and public health. Therefore, urban heat mitigation should not be treated only as an environmental or planning issue. It should also be examined as a problem of energy performance and electrical demand.

The thermal behaviour of urban surfaces depends on several physical properties. Albedo determines how much solar radiation is reflected by a surface. Emissivity describes how effectively a surface emits long-wave thermal radiation. Thermal mass shows how much heat a material can store and how slowly it releases that heat when the surrounding temperature decreases. These properties are important because they connect the physics of heat transfer with the operation of heating, ventilation and cooling systems in buildings.

The choice of urban surface materials affects more than the temperature of the surface itself. It can also change the thermal conditions around buildings and, in some cases, the indoor environment. Salvati et al. (2022), for example, show that reflective materials can modify urban canyon albedo and influence both outdoor microclimate and indoor conditions. However, this does not mean that higher reflectivity is always the best solution. As noted by Yang et al. (2015), the effects of high-albedo materials depend on the scale of application and on the surrounding urban context. Therefore, in this study, surface optimization is treated as an engineering trade-off rather than as a simple replacement of conventional materials.

Green infrastructure also contributes to urban cooling. Trees, parks, green roofs and other vegetated surfaces reduce heat mainly through shading and evapotranspiration. Bowler et al. (2010) found that urban green areas are generally cooler than surrounding built-up areas, while Marando et al. (2022) showed that urban green infrastructure can reduce temperatures in European cities. In the present study, green infrastructure is not examined as a separate landscape element. It is treated as one of the physical factors that modifies urban heat transfer and cooling demand.

A stronger connection is needed between urban microclimate analysis and building energy assessment. Sezer et al. (2023) note that coupled modelling strategies can improve building energy simulations because they take into account the influence of local outdoor conditions. This connection is especially important for smart urban environments, where energy efficiency, climate adaptation and decision-support systems need to work together. The model also fits within the broader development of intelligent engineering systems, where digital readiness and human–AI interaction are important for applying data-driven decision support in practice (Peneva & Andreev, 2023; Koleva, 2024).

The aim of this study is to develop and apply a simplified electro-physical KPI-based assessment model for evaluating how urban surface properties and green infrastructure may influence Urban Heat Island intensity and electrical cooling demand. The model is applied to Sofia Municipality through a case-study and scenario-based analysis. The main focus is the relationship between surface heat transfer, urban temperature behaviour and the electrical energy required for cooling.

ELECTRO-PHYSICAL BACKGROUND

Heat Transfer in Urban Surface Systems

The thermal behaviour of urban surfaces is mainly governed by conduction, convection and radiation. These three mechanisms explain how artificial materials absorb, store and release heat in the urban environment.

Conduction is the transfer of heat through solid materials such as asphalt, concrete, brick, glass and building envelopes. In cities, many of these materials have high thermal conductivity and high heat capacity. They absorb solar energy during the day and release part of the stored heat during the evening and night. This delayed heat release contributes to higher night-time urban temperatures.

In simplified form, conductive heat flow can be described by Fourier's law:

$$q = -k \frac{dT}{dx} \quad (1)$$

where q is the heat flux, k is the thermal conductivity of the material, and $\frac{dT}{dx}$ is the temperature gradient. The equation shows that heat transfer depends on both the material properties and the temperature difference across the material. In an urban context, this is important because asphalt, concrete and other dense materials can store and transfer heat for many hours after solar exposure.

Convection describes the exchange of heat between urban surfaces and the surrounding air. When roads, facades or roofs become hot, they warm the adjacent air. The intensity of this process depends on wind speed, surface temperature, street geometry and building density. Dense urban forms can reduce air movement and trap warm air between buildings.

During the day, radiation is usually the main process behind the heating of urban surfaces, especially in clear weather. Roads, roofs, pavements and façades receive short-wave solar radiation and then release part of the accumulated energy as long-wave heat radiation. The intensity of this process depends strongly on the surface itself. Dark, low-albedo materials absorb more solar energy, while light-coloured or reflective surfaces limit this absorption. After sunset, the cooling process is also affected by the form of the city. In compact areas, closely spaced buildings reduce the exposure of streets and surfaces to the open sky, which slows radiative heat loss and helps retain heat for a longer time.

The overall urban energy balance can be expressed in simplified form as:

$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S \quad (2)$$

where Q^* is net radiation, Q_F is anthropogenic heat, Q_H is sensible heat flux, Q_E is latent heat flux, and ΔQ_S is heat storage. In highly urbanized areas, sensible heat and heat storage usually increase, while latent heat decreases because vegetation and permeable surfaces are replaced by impervious materials. This imbalance is one of the main physical causes of urban overheating.

Albedo, Emissivity and Thermal Mass

Urban surface properties have a direct influence on heat transfer. The most important parameters for this study are albedo, emissivity and thermal mass.

Albedo is the ratio between reflected and incoming solar radiation. It ranges from 0 to 1. Dark materials such as asphalt and conventional dark roofs usually have low albedo and absorb a large part of solar radiation. Light-coloured materials, reflective pavements and cool roofs have higher albedo and can reduce heat absorption. Santamouris (2014) reviews reflective and green roof technologies as practical strategies for urban heat mitigation and energy savings.



Emissivity describes how effectively a surface emits long-wave thermal radiation. Most urban materials have relatively high emissivity, but their overall thermal behaviour depends not only on emissivity. It also depends on albedo, heat capacity, thickness and exposure to solar radiation. A surface may release heat efficiently, but if it absorbs too much solar radiation during the day, it can still reach high temperatures.

Thermal mass describes the ability of a material to store heat. Concrete, brick, stone and asphalt have high thermal mass. These materials can absorb heat during the day and release it later, when the surrounding air becomes cooler. In buildings, thermal mass can be useful when it is properly controlled. In dense urban environments, however, high thermal mass often contributes to night-time warming and higher cooling demand.

These three properties are important because they connect surface physics with electrical energy performance. When urban surfaces absorb and store more heat, outdoor temperatures rise. As a result, buildings need more cooling, and this increases electrical energy consumption. For this reason, albedo, emissivity and thermal mass are not only material characteristics. They are also energy-relevant parameters in smart urban environments.

Urban Heat Island and Electrical Cooling Demand

The Urban Heat Island effect describes the temperature difference between an urban area and its surrounding rural or less built-up environment. In this study, this difference is used as a physical indicator of urban overheating and as an input for estimating cooling-related electricity demand.

The Urban Heat Island intensity is calculated as:

$$\Delta T_{\text{UHI}} = T_{\text{urban}} - T_{\text{rural}} \quad (3)$$

where ΔT_{UHI} is the Urban Heat Island intensity, T_{urban} is the average urban temperature, and T_{rural} is the reference temperature of the surrounding non-urban area.

This temperature difference is important for building operation because it increases the cooling load. When the surrounding urban air remains warmer, the cooling system has to extract more heat in order to keep the indoor environment within the required comfort range. As a result, the electrical energy required for cooling also increases.

Here, the relationship between Urban Heat Island intensity and cooling-related electricity demand is used as an engineering estimate. The purpose is to connect the urban temperature difference with a comparable cooling-demand indicator, while the full calculation procedure is given in the methodology section. Urban form also affects this relationship. Stewart and Oke (2012) show that local climate conditions vary according to surface cover, building density, height, materials and vegetation. Therefore, electrical cooling demand is influenced not only by regional weather, but also by the local urban context around the building. The problem may become more critical during heat waves. Li and Bou-Zeid (2013) show that heat waves and the Urban Heat Island effect can reinforce each other. This interaction can increase thermal stress in cities and raise the need for mechanical cooling during the hottest hours of the day.

In this study, Urban Heat Island intensity is treated as an electro-physical indicator. It connects surface heat transfer with electrical cooling demand. A reduction in urban overheating is therefore interpreted not only as an improvement in microclimate, but also as a possible reduction in electricity use for cooling.

Green Infrastructure and Reflective Surfaces as Cooling Modifiers

Green infrastructure and reflective surfaces are treated in this study as cooling modifiers. They do not remove the Urban Heat Island effect completely, but they can change the way heat is absorbed, stored and released in the urban environment.

Green infrastructure includes trees, parks, green roofs, green walls and vegetated corridors. Its cooling effect is mainly related to shading and evapotranspiration. Shading reduces the amount of solar radiation that reaches roads, pavements, facades and roofs. Evapotranspiration uses part of the available energy for water evaporation instead of surface heating. As a result, vegetated areas can reduce surface temperature and improve local thermal conditions.

Norton et al. (2015) argue that green infrastructure should be planned according to local heat exposure, urban form and vulnerability. This is important because the same amount of vegetation may have different cooling effects in different parts of the city. A large park can reduce temperature in its surrounding area, but street trees may be more effective in dense urban streets where pedestrians, facades and pavements are directly exposed to solar radiation.



Marando et al. (2022) show that urban green infrastructure can reduce temperatures in European cities. Bartesaghi-Koc et al. (2020) also demonstrate that different green infrastructure types have different seasonal cooling capacities. For this reason, green infrastructure should not be evaluated only by total area. Its position and type within the urban fabric are also important.

Reflective materials are included in the model as a practical surface intervention. Their role is to reduce heat absorption from roofs, pavements and facades and, in this way, to influence local temperature and cooling demand. Santamouris (2014) reports that cool materials can support urban heat mitigation and energy savings when they are used appropriately. At the same time, their effect depends on the surrounding urban form. Salvati et al. (2022) show that reflective materials can influence both outdoor and indoor microclimates. Therefore, in this study, albedo improvement is treated as one element of a combined strategy, together with vegetation, urban geometry and energy-performance indicators.

In the present model, green infrastructure and reflective surfaces are treated as intervention variables. They modify the surface energy balance and influence both Urban Heat Island intensity and electrical cooling demand. In this way, physical changes in the urban environment are linked with measurable energy-performance indicators.

The physical processes discussed in this section provide the basis for the modelling framework used in the study. The next section translates these relationships into a KPI-based calculation procedure for comparing baseline and optimized urban scenarios.

METHODOLOGY: ELECTRO-PHYSICAL KPI-BASED MODELLING FRAMEWORK

General Modelling Approach

The methodology is based on a quantitative electro-physical model that links urban surface conditions with electrical cooling demand. The model is designed for scenario comparison. It compares a baseline urban condition with an optimized condition in which surface reflectivity, green infrastructure and energy-performance assumptions are improved. The modelling logic follows three steps.

First, the thermal condition of the urban environment is described through surface and spatial indicators. These include green infrastructure share, impervious surface share, average surface albedo and the temperature difference between urban and non-urban areas. Second, the thermal condition is translated into Urban Heat Island intensity. Third, the change in Urban Heat Island intensity is connected with electrical cooling demand and related CO₂ emissions.

This approach does not aim to replace detailed building energy simulation or computational fluid dynamics. The model should therefore be understood as a simplified electro-physical assessment framework, not as a fully validated dynamic simulation. It does not perform computational fluid dynamics, building-level energy simulation or measured HVAC load validation. Its purpose is to provide a transparent early-stage comparison of urban surface scenarios when detailed measured data are not available. This is useful in early-stage smart city planning, where detailed building-level measurements are not always available. The model follows the idea that urban microclimate and building energy performance should be considered together. This modelling choice follows the argument of Sezer et al. (2023), who show that building energy performance is better interpreted when the surrounding urban microclimate is also taken into account. In the present study, this link is applied in a simplified form through a KPI-based framework that connects local thermal conditions with cooling-related electricity demand. In this sense, the proposed scenario-based framework follows a broader modelling direction in which adaptive energy-flow control, hybrid predictive analysis and stochastic uncertainty propagation are used to support smart urban and cyber-physical systems (Vasilev, 2026a, 2026b, 2026c). Figure 1 shows the modeling framework based on electro-physical key performance indicators (KPIs).

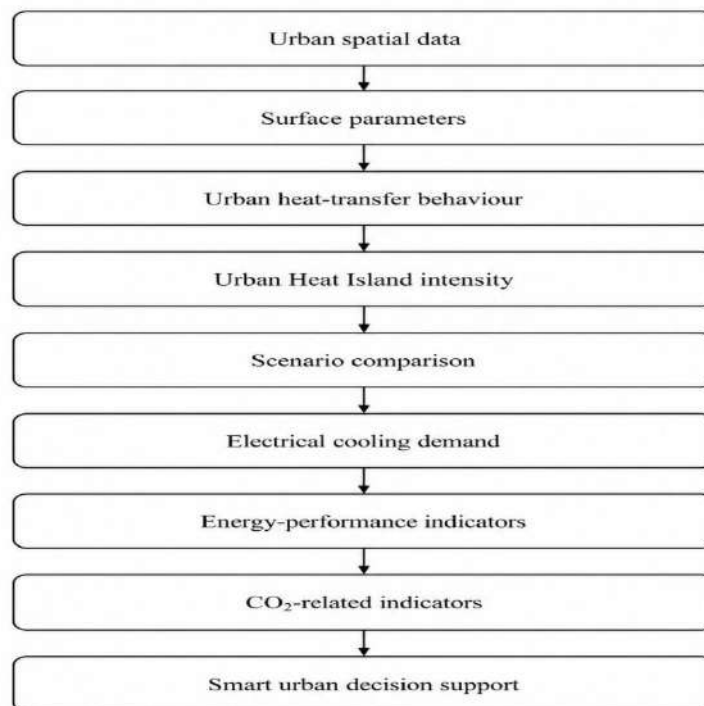


Figure 1. Electro-physical KPI-based modelling framework.

Input Parameters

The model uses input parameters that describe the urban environment from both physical and energy-performance perspectives. The parameters are grouped into four categories: spatial indicators, surface-property indicators, microclimate indicators and energy indicators.

The spatial indicators describe the size and structure of the urban area. They include total municipal area, urbanized territory, agricultural land, forest area, water areas and population. These indicators are needed in order to distinguish the compact urban zone from the surrounding non-urban or semi-natural zones.

The surface-property indicators describe the thermal behaviour of the urban fabric. The most important indicators are average surface albedo, impervious surface share and green infrastructure share. These variables are used to represent the ability of the urban surface to absorb, store or reduce heat. The microclimate indicators describe the thermal difference between the urban and non-urban environment. The main indicator is Urban Heat Island intensity, calculated as the difference between the average urban temperature and the rural or semi-natural reference temperature. The energy indicators describe the effect of urban overheating on cooling-related electricity demand. These include baseline electrical cooling demand, optimized cooling demand, cooling energy savings and CO₂ emissions related to electricity consumption. The input parameters applied in the model are presented in Table 1.

Table 1. Main input parameters of the electro-physical KPI-based model.

Parameter	Symbol	Unit	Role in the model
Urban temperature	T _{urban}	°C	Defines thermal condition of the urban zone
Rural/reference temperature	T _{rural}	°C	Reference value for UHI calculation
Urban Heat Island intensity	ΔT _{UHI}	°C	Main microclimate stress indicator
Green infrastructure share	GI	%	Represents vegetation-based cooling potential
Impervious surface share	IS	%	Represents heat-absorbing urban surfaces
Average surface albedo	A	-	Represents surface reflectivity



Parameter	Symbol	Unit	Role in the model
Baseline cooling demand	$E_{cool,base}$	kWh or index	Cooling demand before optimization
Optimized cooling demand	$E_{cool,opt}$	kWh or index	Cooling demand after optimization
Electricity emission factor	EF_{el}	kg CO ₂ /kWh	Used to estimate CO ₂ emissions
Cooling energy improvement	η_{cool}	%	Measures energy-performance improvement

The model can work with measured data, estimated data or normalized index values. Miller et al. (2020) show that well-documented energy datasets are useful for benchmarking and energy analysis. In this study, spatial and land-use data for Sofia Municipality are combined with scenario-based assumptions. This makes it possible to compare baseline and optimized urban conditions even when detailed building-level electricity measurements are not available.

Case Study Area: Sofia Municipality

Sofia Municipality provides a suitable case study because it contains a compact built-up area surrounded by agricultural, forest and semi-natural territories. This spatial contrast is useful for comparing urban and non-urban thermal conditions. In the present model, this comparison supports the assessment of Urban Heat Island intensity and its connection with surface heat accumulation and cooling-related electricity demand.

The municipality has a population of 1,295,931 inhabitants according to the National Statistical Institute data for Sofia as of 31 December 2024 (National Statistical Institute [NSI], 2025). Sofia Municipality covers a territory of 1,311 km², including 245.5 km² of populated areas and urbanized territories, 509 km² of agricultural land, 466.5 km² of forest areas and approximately 40 km² of watercourses and water areas (Sofia Municipality, n.d.). This land-use structure is important for the model. The urbanized territory represents the main zone of artificial surfaces, buildings, roads, pavements and energy consumption. It is also the zone where higher heat storage and stronger cooling demand are expected. In contrast, agricultural and forest areas provide a reference background for lower surface temperatures and reduced heat accumulation.

The difference between the compact urban zone and the surrounding non-urban territories allows the model to define a reference condition for Urban Heat Island assessment. In this study, the urbanized area is treated as the main heat-producing zone, while agricultural and forest areas are used as semi-natural reference zones. Water areas are considered separately because their thermal behaviour differs from both built-up and vegetated land.

The baseline spatial characteristics of Sofia Municipality are summarized in Table 2.

Table 2. Baseline spatial and land-use characteristics of Sofia Municipality.

Indicator	Value	Unit	Relevance for the model
Population	1,295,931	persons	Defines the scale of urban activity and energy demand
Total municipal area	1,311	km ²	Defines the spatial boundary of the case study
Urbanized territory	245.5	km ²	Main zone for heat accumulation and electrical cooling demand
Urbanized share	18.73	%	Indicates the concentration of artificial surfaces
Agricultural land	509	km ²	Semi-natural reference zone for thermal comparison
Forest area	466.5	km ²	Natural cooling and reference zone
Agricultural and forest areas	975.5	km ²	Main non-urban comparison area
Agricultural and forest share	74.41	%	Shows the contrast between urban and non-urban territories
Water areas	40	km ²	Should be interpreted separately in thermal analysis

Note. Population data are based on NSI data for Sofia as of 31 December 2024. Territorial and land-use data are based on the official geographical characteristics of Sofia Municipality (NSI, 2025; Sofia Municipality, n.d.).

The land use structure of Sofia Municipality is shown in Figure 2.

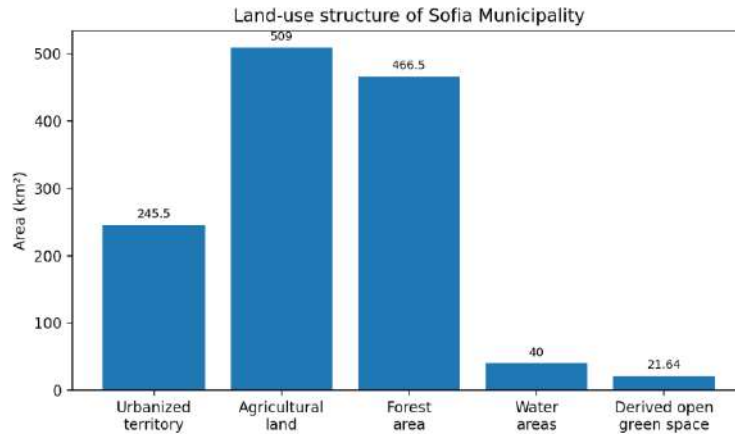


Figure 2. Land use structure of Sofia Municipality.

Source: Author’s visualization based on Sofia Municipality geographical data and derived open green-space calculations using the Sofia Green City Action Plan indicator.

The case-study structure supports the electro-physical logic of the model. The compact urbanized area is expected to have higher heat-storage capacity because of its artificial materials and dense built environment. The surrounding agricultural and forest areas provide a lower-temperature reference. This makes Sofia Municipality suitable for scenario-based assessment of how changes in surface properties and green infrastructure may influence Urban Heat Island intensity and cooling-related electricity demand.

Derived Density and Green Infrastructure Indicators

Several derived indicators were calculated in order to describe the relationship between population concentration, urbanized territory and green infrastructure availability. These indicators are used to support the interpretation of the electro-physical model, because population density and land-use structure influence both heat accumulation and cooling-related energy demand.

The municipal population density was calculated by dividing the population by the total municipal area:

$$D_{mun} = \frac{P}{A_{mun}} \tag{4}$$

where D_{mun} is the municipal population density, P is the population, and A_{mun} is the total municipal area.

The population density within the urbanized territory was calculated as:

$$D_{urb} = \frac{P}{A_{urb}} \tag{5}$$

where D_{urb} is the population density of the urbanized territory, and A_{urb} is the area of the urbanized territory.

For Sofia Municipality, the calculated municipal population density is approximately 988.5 persons/km². The density within the urbanized territory is much higher, approximately 5,278.7 persons/km². This difference shows that population and artificial surfaces are concentrated in the compact urban zone, where higher heat storage and cooling demand are expected.

The estimated open green-space area was calculated using the open green-area ratio reported in the Sofia Green City Action Plan, namely 167 ha per 100,000 inhabitants (PwC Advisory, 2020, p. 26):

$$A_{green} = \frac{P}{100000} \cdot 167 \tag{6}$$

where A_{green} is the estimated open green-space area in hectares.

For Sofia Municipality, this gives an estimated open green-space area of 2,164.2 ha, or 21.64 km². This corresponds to approximately 16.7 m² of open green space per inhabitant.

The share of open green space within the total municipal area was calculated as:

$$S_{green,mun} = \frac{A_{green}}{A_{mun}} \times 100 \tag{7}$$

The share of open green space within the urbanized territory was calculated as:

$$S_{green,urb} = \frac{A_{green}}{A_{urb}} \times 100 \tag{8}$$



The results show that open green space represents approximately 1.65% of the total municipal area and 8.82% of the urbanized territory. The second value is more relevant for the present study, because vegetation within the compact urban zone has a more direct influence on shading, evapotranspiration, surface temperature and cooling demand. The derived indicators are summarized in Table 3.

Table 3. Derived density and green infrastructure indicators for Sofia Municipality.

Derived indicator	Formula / basis	Result	Unit	Interpretation
Municipal population density	P / A_{mun}	988.5	persons/km ²	General density of the municipality
Urbanized-area population density	P / A_{urb}	5,278.7	persons/km ²	Density of the compact urban zone
Open green-space ratio	Reported value	167	ha/100,000 inhabitants	Availability of open green space
Estimated open green-space area	$P \times 167 / 100,000$	2,164.2	ha	Estimated total open green space
Estimated open green-space area	Converted from hectares	21.64	km ²	Area used in spatial comparison
Open green space per inhabitant	$167 \text{ ha} / 100,000 \text{ inhabitants}$	16.7	m ² /person	Individual green-space availability
Open green-space share of total area	$21.64 / 1,311 \times 100$	1.65	%	Green-space share at municipal scale
Open green-space share of urbanized area	$21.64 / 245.5 \times 100$	8.82	%	Key indicator for urban cooling potential

Note. Density indicators are author’s calculations based on NSI population data and Sofia Municipality territorial data. Open green-space indicators are calculated using the ratio of 167 ha per 100,000 inhabitants reported in the Sofia Green City Action

Plan (NSI, 2025; Sofia Municipality, n.d.; PwC Advisory, 2020).

These indicators show that Sofia Municipality has large agricultural and forest areas at the municipal scale, but a more limited share of open green space within the compact urbanized area. For the electro-physical model, this distinction is important. Green areas outside the dense urban zone may contribute to the wider thermal background, but green infrastructure inside the urbanized territory has a more direct effect on surface temperature, pedestrian-level microclimate and cooling-related electricity demand.

Baseline and Optimized Scenario Design

The assessment is based on two cases. The first describes the existing urban condition, including the current surface structure and energy-performance assumptions. The second represents an improved case, where selected surface and cooling-related parameters are modified in order to evaluate the potential effect of urban interventions. The baseline scenario is characterized by the current share of green infrastructure, conventional urban materials and the existing structure of the urbanized territory. In this scenario, the compact urban area contains a high proportion of artificial surfaces such as asphalt, concrete, roofs, pavements and facades. These surfaces contribute to heat absorption, heat storage and higher outdoor temperatures.

The optimized scenario introduces three main changes. First, the share of green infrastructure is increased in order to improve shading and evapotranspiration. Second, average surface albedo is increased through the use of lighter and more reflective materials. Third, energy-performance assumptions are improved in order to represent more efficient cooling operation and lower electricity demand.

The scenario design is not intended to reproduce every physical process in the urban environment. Its purpose is to provide a transparent comparison between the existing condition and a technically improved condition. This makes it possible to estimate the expected direction and scale of change in Urban Heat Island intensity, electrical cooling demand and CO₂ emissions related to electricity use.

The main assumptions used in the two scenarios are presented in Table 4.



Table 4. Baseline and optimized scenario assumptions.

Parameter	Baseline scenario	Optimized scenario	Expected effect
Green infrastructure	Existing level	Increase by 10 percentage points	More shading and evapotranspiration
Average surface albedo	Current urban condition	Increase by +0.15	Lower solar heat absorption
Impervious surfaces	Dominant in dense urban zones	Partly replaced or modified	Reduced heat storage
Urban temperature	Higher due to artificial surfaces	Lower due to combined interventions	Reduced UHI intensity
Electrical cooling demand	Baseline index = 100	Reduced index value	Lower cooling-related electricity use
CO ₂ emissions from cooling electricity	Baseline index = 100	Reduced index value	Lower electricity-related emissions

The optimized scenario combines vegetation-based and material-based interventions. Green infrastructure mainly affects the urban energy balance through shading and evapotranspiration. Reflective materials mainly affect the radiation balance by reducing heat absorption. When these measures are applied together, they can reduce surface temperature and improve the thermal behaviour of the urban environment.

In this study, cooling demand can be expressed either as an energy value or as a normalized index. The index approach is used when detailed electricity data at building level are not available. For comparison, the baseline condition is assigned a value of 100, while the optimized condition is expressed as a lower relative value. This makes it possible to evaluate the expected change in energy performance without presenting the results as measured building-level electricity consumption.

At this stage of the analysis, the scenario comparison is used mainly as a screening tool. Detailed measurements for individual buildings are not available, and a full dynamic simulation is outside the scope of the study. For that reason, the model tests the likely direction of change when surface reflectivity and green infrastructure are modified. The results should therefore be read as indicative estimates of cooling-demand response, not as measured electricity savings for Sofia Municipality. A similar link between additional green infrastructure and cooling-energy benefits in urban building environments is discussed by Mohammed et al. (2023). To avoid ambiguity between real data, derived indicators and scenario assumptions, the data categories used in the model are summarized in Table 5.

Table 5. Data type and role in the model.

Data group	Source / status	Role in the model
Population	NSI, 2025	Defines the scale of urban activity
Municipal area	Sofia Municipality, n.d.	Defines spatial boundary
Urbanized territory	Sofia Municipality, n.d.	Defines the main heat-producing zone
Agricultural and forest areas	Sofia Municipality, n.d.	Define reference zones
Open green-space indicators	Author’s calculations based on NSI, 2025; Sofia Municipality, n.d.; PwC Advisory, 2020	Support cooling-potential interpretation
Albedo improvement	+0.15	Represents reflective surface intervention
Green infrastructure increase	+10 percentage points	Represents vegetation intervention
Electrical cooling demand	Baseline = 100	Estimates relative energy change



Data group	Source / status	Role in the model
CO ₂ emissions	Based on emission factor	Estimates electricity-related environmental effect
UHI, cooling demand and CO ₂ reduction ranges	Literature-informed scenario ranges	Used for sensitivity-based interpretation, not direct empirical validation

Calculation Procedure

The calculation procedure follows a step-by-step logic. The aim is to connect urban surface conditions with Urban Heat Island intensity, electrical cooling demand and CO₂ emissions related to electricity use. The same calculation sequence is applied to both the baseline and optimized scenarios.

First, the intensity of the urban heat island is calculated as the difference between the average urban temperature and the rural reference temperature or semi-natural temperature by equation (1).

Second, the change in Urban Heat Island intensity between the baseline and optimized scenario is calculated as:

$$\Delta T_{red} = \Delta T_{UHI,base} - \Delta T_{UHI,opt} \quad (9)$$

where ΔT_{red} is the reduction in Urban Heat Island intensity, $\Delta T_{UHI,base}$ is the baseline Urban Heat Island intensity, and $\Delta T_{UHI,opt}$ is the optimized scenario Urban Heat Island intensity.

The percentage reduction in Urban Heat Island intensity is calculated as:

$$R_{UHI} = \frac{(\Delta T_{UHI,base} - \Delta T_{UHI,opt})}{\Delta T_{UHI,base}} \times 100 \quad (10)$$

where R_{UHI} is the percentage reduction in Urban Heat Island intensity.

Third, the electrical cooling demand is estimated by using a simplified temperature-load relationship:

$$E_{cool} = E_{base} + \alpha \cdot \Delta T_{UHI} \quad (11)$$

where E_{cool} is the estimated electrical energy demand for cooling, E_{base} is the reference cooling demand, α is the temperature-related energy coefficient, and ΔT_{UHI} is the Urban Heat Island intensity.

Fourth, the reduction in electrical cooling demand between the two scenarios is calculated as:

$$\Delta E_{cool} = E_{cool,base} - E_{cool,opt} \quad (12)$$

where ΔE_{cool} is the reduction in electrical cooling demand, $E_{cool,base}$ is the cooling demand in the baseline scenario, and $E_{cool,opt}$ is the cooling demand in the optimized scenario.

The percentage improvement in cooling energy performance is calculated as:

$$\eta_{cool} = \frac{(E_{cool,base} - E_{cool,opt})}{E_{cool,base}} \times 100 \quad (13)$$

where η_{cool} is the cooling energy improvement in percent.

Fifth, CO₂ emissions related to cooling electricity use are estimated by applying an electricity emission factor:

$$CO_2 = E_{cool} \cdot EF_{el} \quad (14)$$

where CO_2 represents emissions related to cooling electricity use, E_{cool} is the electrical cooling demand, and EF_{el} is the electricity emission factor.

The avoided CO₂ emissions between the baseline and optimized scenario are calculated as:

$$\Delta CO_2 = (E_{cool,base} - E_{cool,opt}) \cdot EF_{el} \quad (15)$$

where ΔCO_2 represents avoided CO₂ emissions.

The procedure is used to keep the connection between surface-related changes and energy indicators explicit. It should not be read as a calculation of the electricity use of each building in Sofia Municipality. The aim is more limited: to estimate, at scenario level, how changes in surface conditions may affect cooling-related electricity demand.

Model Outputs and Interpretation

The outputs are interpreted at scenario level. They compare the baseline and optimized conditions, without representing measured electricity use for individual buildings. The main indicators are listed in Table 6.



Table 6. Model outputs and interpretation.

Output	Meaning	Use in the study
Urban Heat Island intensity	Thermal difference between urban and reference area	Indicates urban overheating
UHI reduction	Difference between baseline and optimized scenario	Measures thermal improvement
Electrical cooling demand	Cooling-related electricity indicator	Links microclimate with energy use
Cooling energy improvement	Relative reduction in cooling demand	Compares scenario performance
CO ₂ emissions	Electricity-related emissions from cooling demand	Shows environmental effect
Avoided CO ₂ emissions	Difference between baseline and optimized scenario	Estimates potential benefit

The interpretation follows the modelling chain shown in Figure 1. If the optimized scenario reduces Urban Heat Island intensity, lower outdoor thermal stress is expected. If outdoor thermal stress decreases, electrical cooling demand may also decrease. If cooling demand decreases, electricity-related CO₂ emissions are expected to decrease as well. This makes the outputs useful for early-stage decision support in smart urban environments.

RESULTS AND DISCUSSION

Baseline Urban Structure and Thermal Interpretation

The baseline spatial data show a distinct difference between the compact urbanized part of Sofia Municipality and the surrounding agricultural and forest territories. This difference is important for the thermal interpretation of the case study. The built-up zone concentrates artificial surfaces with higher heat-storage capacity, while the non-urban areas provide conditions for lower heat accumulation and stronger natural cooling.

The urbanized territory concentrates population, buildings, roads, pavements and artificial surfaces. It is therefore the main zone where surface heat absorption and electrical cooling demand are expected to be higher. The surrounding agricultural and forest territories provide a useful reference background for evaluating the Urban Heat Island effect.

The difference between municipal population density and urbanized-area population density supports this interpretation. The urbanized area is not only physically compact, but also functionally intensive. Higher density usually means more buildings, more transport activity, more artificial surfaces and higher electricity demand during warm periods. Similar links between surface urban heat island patterns and land-cover drivers have been observed in large-scale urban studies (Zhou et al., 2014).

The open green-space indicators show another important result. The share of open green space within the urbanized territory is more relevant for cooling-demand interpretation than the municipal-scale value, because green space inside the compact urban area has a more direct effect on shading, evapotranspiration and local surface temperature.

These results suggest that Sofia has significant natural and semi-natural territories at the municipal scale, but the cooling function inside the dense urban area may still be limited. A city may have large forest and agricultural areas within its administrative boundary and still experience strong overheating in its compact built-up districts. For this reason, the spatial distribution of green infrastructure is as important as its total amount.

This spatial structure makes Sofia Municipality appropriate for the scenario-based electro-physical assessment used in the study. The compact urbanized area is treated as the main zone of heat accumulation, while the surrounding agricultural, forest and semi-natural territories serve as a reference background for thermal comparison. This structure allows the model to evaluate how changes in surface reflectivity and green infrastructure may influence Urban Heat Island intensity and cooling-related electricity demand.

Scenario-Based Thermal and Energy Performance

The optimized scenario was designed to test the combined effect of surface and microclimate interventions. The scenario includes an increase in green infrastructure by 10 percentage points and an increase in average surface albedo by +0.15. These changes



represent a combined strategy based on vegetation-based cooling and material-based cooling. Under the optimized scenario, lower heat accumulation is expected in the compact urbanized area. The assumed increase in green infrastructure affects the thermal balance through shading and evapotranspiration. The increase in surface albedo works in another way, by reducing the share of solar radiation absorbed by roofs, pavements and façades. In combination, these changes modify the surface energy balance and support a lower level of urban overheating.

The scenario-based sensitivity assessment suggests that the optimized scenario may reduce Urban Heat Island intensity by approximately 18–32%. This range should not be interpreted as a measured value for Sofia Municipality. It represents a literature-informed and parameter-based scenario range under the selected intervention assumptions. This range reflects the assumption that the cooling effect depends on the local spatial structure, the distribution of vegetation and the type of surface materials used. It is a scenario-based estimate of the potential improvement under the selected intervention assumptions.

The reduction in Urban Heat Island intensity is connected with lower electrical cooling demand. Under the optimized scenario, the model estimates a reduction in cooling-related electricity demand of approximately 12-24%. This result is important because it translates microclimatic improvement into an energy-performance outcome. It shows that surface interventions may have an effect beyond outdoor comfort. They may also reduce the electricity required for cooling during warm periods.

The reduction in cooling demand is also reflected in the CO₂ indicator. In the optimized scenario, electricity-related CO₂ emissions decrease by about 10–22%. This range should be interpreted as a scenario estimate, since the final value depends on the selected electricity emission factor and on the assumed decrease in cooling-related demand.

The scenario-based performance results are summarized in Table 7 and Figure 3.

Table 7. Baseline and optimized scenario performance.

Indicator	Baseline scenario	Optimized scenario	Expected change
Green infrastructure	Current level	+10 percentage points	Increased shading and evapotranspiration
Average surface albedo	Current condition	+0.15	Lower heat absorption
Urban Heat Island intensity	Reference value	Lower simulated value	18-32% reduction
Electrical cooling demand	Index = 100	Index = 76-88	12-24% reduction
CO ₂ emissions from cooling electricity	Index = 100	Index = 78-90	10-22% reduction

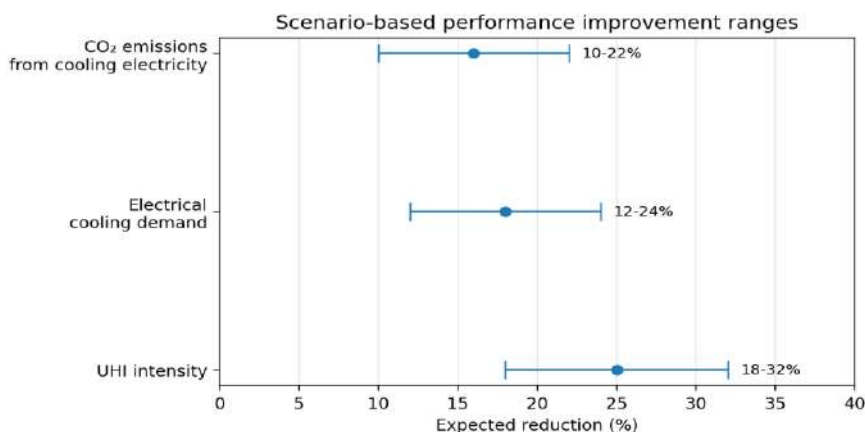


Figure 3. Scenario-based performance improvement ranges.

The results show that the strongest effect is achieved when interventions are combined. Green infrastructure alone may reduce local temperature, but its effect depends on location, density and vegetation type. Reflective surfaces may reduce heat absorption, but their impact also depends on urban geometry and exposure. When both measures are used together, they can support a more balanced reduction in urban heat accumulation and cooling demand.



From an electro-physical perspective, the most important result is the connection between surface modification and electrical cooling demand. The optimized scenario does not only improve the thermal condition of the urban environment. It also indicates a possible reduction in the electricity required for cooling. This supports the main argument of the study: urban surface design can be interpreted as part of smart urban energy management.

Interpretation of Electrical Cooling Demand Reduction

The reduction in electrical cooling demand is interpreted only at scenario level. It is not a measured value for the individual buildings in Sofia Municipality. The result shows the likely direction and approximate scale of change that may occur when urban surface conditions are improved. The effect is expected to be stronger in dense urban zones. These areas usually contain more artificial surfaces, higher building density and less vegetation. They also tend to have higher internal heat gains and greater cooling needs. For this reason, interventions in compact urban districts may produce larger energy benefits than interventions in areas with lower density and more natural cover.

The estimated reduction also has relevance for peak demand. Cooling systems often operate most intensively during the hottest hours of the day. If urban overheating is reduced, the electrical load during these hours may also decrease. This is important for urban energy systems because peak cooling demand can put additional pressure on electrical infrastructure.

The model does not assume that surface interventions alone can solve the cooling-energy problem. Building envelope quality, HVAC efficiency, occupancy patterns, internal heat gains and user behaviour also influence electricity demand. Therefore, the results should be understood as the potential contribution of urban surface improvement within a broader energy-efficiency strategy.

From a smart urban systems perspective, this finding supports the use of surface and microclimate indicators in energy decision-making. Urban heat mitigation can be connected with electrical energy management, especially when scenario models are used to identify areas where interventions may have the strongest effect.

CO₂ Emissions and Environmental Effect

The reduction in cooling-related electricity demand also affects CO₂ emissions. In the model, emissions are calculated by applying an electricity emission factor to the estimated electrical cooling demand. Therefore, when the optimized scenario reduces cooling demand, it also reduces the related CO₂ emissions.

The CO₂ reduction is reported as a scenario-level estimate. It should not be read as measured emissions from all buildings in Sofia Municipality. The final value depends mainly on the assumed reduction in cooling electricity demand and on the emission factor used in the calculation. If the electricity mix becomes less carbon-intensive, the emissions related to cooling will also be lower. If the mix remains more carbon-intensive, the same amount of electricity use will lead to higher CO₂ emissions. The estimated CO₂ reduction should not be understood as an isolated environmental indicator. It is connected with the whole electro-physical chain used in the model: surface properties influence heat accumulation, heat accumulation influences Urban Heat Island intensity, Urban Heat Island intensity affects cooling demand, and cooling demand determines electricity-related emissions.

From a smart city perspective, this connection is useful for decision support. It allows urban planners, engineers and energy managers to compare interventions not only by their thermal effect, but also by their possible contribution to lower electricity use and reduced emissions.

Implications for Smart Urban Energy Management

The proposed model has practical value for smart urban energy management because it connects urban surface conditions with cooling-related electricity demand. This connection is important for cities where heat stress, building density and electricity consumption increase at the same time.

In many urban energy assessments, cooling demand is treated mainly as a building-level problem. The results of this study suggest that the surrounding urban environment should also be considered. A building located in a dense and overheated district may require more cooling than a similar building located near shaded, vegetated or lower-temperature areas. For this reason, energy management in smart cities should include not only building technologies, but also urban surface and microclimate indicators.

The model can support early-stage decision-making. It allows different scenarios to be compared before detailed technical design is carried out. For example, decision-makers can compare the expected effect of increasing green infrastructure, improving surface



reflectivity or combining both measures. The model does not provide a full dynamic simulation, but it gives a transparent way to estimate the possible direction and scale of energy-performance improvement.

This is useful for smart urban systems because it transforms physical urban characteristics into measurable indicators. Surface albedo, green infrastructure share and Urban Heat Island intensity become part of an energy-performance assessment. In this way, urban planning data can be connected with engineering indicators such as cooling demand, energy savings and electricity-related CO₂ emissions. The model can also be used as a decision-support component in a wider smart city platform. If real sensor data are available, the same logic can be extended with measured surface temperature, air temperature, electricity consumption or building cooling loads. In this case, the model may serve as a bridge between urban monitoring, energy analysis and automated scenario evaluation. Such an extension is consistent with the broader use of digital and data-driven methods for building energy efficiency (Bortolini et al., 2022).

Urban heat mitigation can therefore be treated as part of energy management. Green infrastructure and reflective surfaces are not only environmental or architectural measures; they also influence the electricity needed for cooling. This makes them important for smart urban energy strategies in cities exposed to summer overheating and rising cooling demand.

LIMITATIONS OF THE STUDY

The results should be interpreted with several methodological limitations in mind. The first limitation is related to the scenario-based character of the model. The results show the expected direction and relative scale of change, but they should not be interpreted as direct measurements of electricity consumption or CO₂ emissions from all buildings in Sofia Municipality. The study does not include empirical validation through measured surface temperatures, air temperatures, electricity consumption data or HVAC load profiles.

The second limitation concerns the use of generalized urban indicators. The model works with spatial, surface and energy-performance assumptions at urban scale. It does not include detailed information for each individual building, such as envelope characteristics, HVAC system efficiency, internal heat gains, occupancy schedules or user behaviour. These factors can strongly influence cooling demand at building level.

The third limitation is related to urban morphology. The model includes surface and green infrastructure indicators, but it does not fully represent street-canyon geometry, building height, sky-view factor or local wind conditions. These parameters can change the local thermal behaviour of dense urban areas and may affect the cooling potential of reflective materials and vegetation.

The fourth limitation concerns the estimation of green infrastructure effects. The cooling effect of vegetation depends not only on total green area, but also on tree species, canopy density, irrigation, soil moisture, spatial distribution and maintenance. In this study, green infrastructure is represented through a simplified scenario assumption. This is useful for comparison, but it cannot capture all local ecological and microclimatic differences.

The fifth limitation is connected with the electricity emission factor. CO₂ emissions are calculated from cooling-related electricity demand by using an emission factor. This means that the estimated emissions depend on the assumed carbon intensity of electricity. If the electricity mix changes, the CO₂ results would also change.

Despite these limitations, the model provides a useful early-stage assessment framework. Its purpose is not to replace detailed building simulation, urban climate modelling or measured electricity monitoring. Its value lies in connecting urban surface properties, microclimate indicators and electrical cooling demand in a transparent way. Future research can improve the model by including measured surface temperatures, building-level electricity data, sensor-based microclimate monitoring and more detailed information about urban morphology.

CONCLUSION

This study developed and applied a simplified scenario-based electro-physical assessment model for examining the relationship between urban surface heat transfer and electrical cooling demand in smart urban environments. The model connects physical surface parameters, such as albedo, thermal mass, impervious surfaces and green infrastructure, with Urban Heat Island intensity and cooling-related electricity demand.

The case study of Sofia Municipality showed that the compact urbanized area has a strong contrast with the surrounding agricultural and forest territories. Although the urbanized territory represents a smaller part of the total municipal area, it



concentrates population, buildings, roads, pavements and other artificial surfaces. This makes it the main zone where heat accumulation and cooling demand are expected to be higher.

The scenario-based results suggest that combined surface and vegetation interventions can improve urban thermal performance. The optimized scenario, based on increased green infrastructure and higher surface reflectivity, showed a potential reduction in Urban Heat Island intensity, electrical cooling demand and CO₂ emissions related to cooling electricity use. These results support the idea that urban heat mitigation can also be interpreted as an energy-management measure.

The main contribution of the study is the proposed link between physical urban surface properties and electrical energy performance. The model does not replace detailed building simulation or measured electricity monitoring. Instead, it provides a transparent framework for early-stage assessment and comparison of urban scenarios. This makes it useful for smart city planning, urban energy analysis and decision-support systems.

Future research should extend the model with measured data. Useful additions would include surface temperature measurements, outdoor microclimate monitoring, building-level electricity data, cooling load profiles and more detailed information about urban morphology. Such data would allow the model to be validated more precisely and applied to specific districts, building groups or smart city monitoring platforms.

Overall, the study shows that urban surfaces should be considered not only as architectural or environmental elements, but also as factors influencing electrical cooling demand. This electro-physical perspective can support the design of cooler, more energy-efficient and more resilient smart urban environments.

REFERENCES

1. Bartesaghi-Koc, C., Osmond, P., & Peters, A. (2020). Quantifying the seasonal cooling capacity of “green infrastructure types” (GITs): An approach to assess and mitigate surface urban heat island in Sydney, Australia. *Landscape and Urban Planning*, 203, Article 103893. <https://doi.org/10.1016/j.landurbplan.2020.103893>
2. Bortolini, R., Rodrigues, R., Alavi, H., Vecchia, L. F. D., & Forcada, N. (2022). Digital twins’ applications for building energy efficiency: A review. *Energies*, 15(19), Article 7002. <https://doi.org/10.3390/en15197002>
3. Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning*, 97(3), 147-155. <https://doi.org/10.1016/j.landurbplan.2010.05.006>
4. IEA. (2023). *Energy efficiency 2023*. International Energy Agency.
5. Koleva, N. (2024). Human in cooperation with AI: Next level of intelligent man-machine interaction. *Proceedings of World Multi-Conference on Systemics, Cybernetics and Informatics, WMSCI Conference*. <https://doi.org/10.54808/WMSCI2024.01.292>
6. Li, D., & Bou-Zeid, E. (2013). Synergistic interactions between urban heat islands and heat waves: The impact in cities is larger than the sum of its parts. *Journal of Applied Meteorology and Climatology*, 52(9), 2051-2064. <https://doi.org/10.1175/JAMC-D-13-02.1>
7. Marando, F., Heris, M. P., Zulian, G., Udias, A., Mentaschi, L., Chrysoulakis, N., Parastatidis, D., & Maes, J. (2022). Urban heat island mitigation by green infrastructure in European Functional Urban Areas. *Sustainable Cities and Society*, 77, Article 103564. <https://doi.org/10.1016/j.scs.2021.103564>
8. Miller, C., Kathirgamanathan, A., Picchetti, B., Arjunan, P., Park, J. Y., Nagy, Z., Raftery, P., Hobson, B. W., Shi, Z., & Meggers, F. (2020). The Building Data Genome Project 2, energy meter data from the ASHRAE Great Energy Predictor III competition. *Scientific Data*, 7, Article 368. <https://doi.org/10.1038/s41597-020-00712-x>
9. National Statistical Institute. (2025). Sofia (stolitsa): Statistical data. National Statistical Institute of the Republic of Bulgaria.
10. Mohammed, A., Khan, A., Khan, H. S., & Santamouris, M. (2023). Cooling energy benefits of increased green infrastructure in subtropical urban building environments. *Buildings*, 13(9), Article 2257. <https://doi.org/10.3390/buildings13092257>



11. Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. G. (2015). Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning*, 134, 127-138. <https://doi.org/10.1016/j.landurbplan.2014.10.018>
12. Peneva, G. & Andreev, O. (2023). Assessing Bulgarian SMEs' Maturity for Industry 4.0 Implementing – the Case of Montana Hydraulics Ltd., *Strategies for Policy in Science and Education*, Vol. 31, No 3s, pp. 9-24, Az-buki National Publishing House for Education and Science, ISSN 1310-0270 (Print), ISSN 1314-8575 (Online), DOI: 10.53656/str2023-3s-1-ass
13. PwC Advisory spółka z ograniczoną odpowiedzialnością sp.k. (2020). *The Green City Action Plan: Sofia, Bulgaria*. Prepared for Sofia Municipality; funded by the European Bank for Reconstruction and Development.
14. Salvati, A., Kolokotroni, M., Kotopouleas, A., Watkins, R., Giridharan, R., & Nikolopoulou, M. (2022). Impact of reflective materials on urban canyon albedo, outdoor and indoor microclimates. *Building and Environment*, 207, Article 108459. <https://doi.org/10.1016/j.buildenv.2021.108459>
15. Santamouris, M. (2014). Cooling the cities: A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Solar Energy*, 103, 682-703. <https://doi.org/10.1016/j.solener.2012.07.003>
16. Santamouris, M. (2020). Recent progress on urban overheating and heat island research: Integrated assessment of the energy, environmental, vulnerability and health impact; synergies with global climate change. *Energy and Buildings*, 207, Article 109482. <https://doi.org/10.1016/j.enbuild.2019.109482>
17. Sezer, N., Yoonus, H., Zhan, D., Wang, L., Hassan, I. G., & Rahman, M. A. (2023). Urban microclimate and building energy models: A review of the latest progress in coupling strategies. *Renewable and Sustainable Energy Reviews*, 184, Article 113577. <https://doi.org/10.1016/j.rser.2023.113577>
18. Sofia Municipality. (n.d.). *Geographical characteristics*. Portal of Sofia Municipality.
19. Stewart, I. D., & Oke, T. R. (2012). Local Climate Zones for urban temperature studies. *Bulletin of the American Meteorological Society*, 93(12), 1879-1900. <https://doi.org/10.1175/BAMS-D-11-00019.1>
20. Vasilev, I. (2026). Exemplary Model of AI-Supported Adaptive Optimization Energy Flow Control in SmartCity Microgrids: A Simulation-Based Scenarios. *International Journal of Current Science Research and Review*, 9(4), pp. 1824-1833. DOI: <https://doi.org/10.47191/ijcsrr/V9-i4-14>
21. Vasilev, I. (2026). A Hybrid “ARIMA–ML Regression” Model for Enhanced Predictive Analysis in Cyber-Physical Systems: Conceptual framework and Simulation Evaluation. *International Journal of Current Science Research and Review*, 9(5), pp. 2232-2243. DOI: <https://doi.org/10.47191/ijcsrr/V9-i5-02>
22. Vasilev, I. (2026). A Stochastic Framework for Fully Distributed Control Systems and CPS: From Local State Transitions to Global Uncertainty Propagation. *International Journal of Current Science Research and Review*, 9(6), pp. 2943-2957. DOI: <https://doi.org/10.47191/ijcsrr/V9-i6-01>
23. Yang, J., Wang, Z.-H., & Kaloush, K. E. (2015). Environmental impacts of reflective materials: Is high albedo a “silver bullet” for mitigating urban heat island? *Renewable and Sustainable Energy Reviews*, 47, 830-843. <https://doi.org/10.1016/j.rser.2015.03.092>
24. Zhou, D., Zhao, S., Liu, S., Zhang, L., & Zhu, C. (2014). Surface urban heat island in China's 32 major cities: Spatial patterns and drivers. *Remote Sensing of Environment*, 152, 51-61. <https://doi.org/10.1016/j.rse.2014.05.017>

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