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Evaluation of the Influence of Radiative Thermal Parameters on Thermal and Visual Urban Comfort

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Abstract

In the context of the urban energy transition, this article presents a joint evaluation of the radiative properties of urban materials and thermo-visual perception, based on an integrated modeling of light and thermal exchanges. Solar radiation reflection is simulated using surface albedo values to analyse light diffusion, diffuse illuminance, shading patterns, and glare risk. Thermal impacts are assessed through the mean radiant temperature (MRT), determined by surface emissivity and temperature. The urban radiative balance incorporates shortwave and longwave fluxes (K_{down} , K_{up} , L_{down} , L_{up}) and is complemented by shading indices to evaluate the influence of urban morphology on thermal stress reduction. Finally, visual comfort is assessed using natural glare indicators adapted to urban environments, notably the Daylight Glare Index (DGI) and the Daylight Glare Probability (DGP).

Keywords: Thermo-Visual Comfort, Urban Materials, Radiative Properties, Radiative Balance, Mean Radiant Temperature (Mrt), Urban Morphology, Glare Indices

Introduction

Facing climate change and increasing urbanization, the urban energy transition aims to strengthen the resilience of cities while ensuring the comfort of users in outdoor spaces. Recent studies show that the evaluation of adaptation strategies cannot be limited to energy indicators alone, but must jointly consider thermal comfort and visual comfort, which are closely linked to the radiative properties of urban materials and the built environment morphology [1,2].

Increasing the albedo of urban surfaces has been widely studied as a means to mitigate the urban heat island effect but it can also increase the radiative load received by pedestrians and alter the mean radiant temperature, a key parameter of outdoor thermal comfort [3,4]. Moreover, solar reflection influences luminance and visual contrasts, potentially generating glare in public spaces, which can be assessed using indicators such as DGI and DGP [5].

In this context, this work proposes a joint evaluation of the radiative properties of urban materials and thermo-visual perception through an integrated modelling of thermal and luminous exchanges, in order to identify trade-offs between thermal comfort, visual comfort, and energy performance.

Methodology

This article analyses the influence of radiative parameters on thermal and visual comfort in the city centre of Reims (France). Radiative exchanges, related to solar exposure, material properties, and urban morphology, play a key role in the perception of comfort. The study is based on a comparative analysis of three scenarios: a reference scenario representing the current situation, a high-reflectivity surfaces scenario aimed at evaluating the albedo effect, and a reinforced vegetation scenario designed to assess the impact of greenery on the overall comfort improvement. The figure below illustrates the study area:



Figure 1: Study Area: Reims City Center, France

Radiative simulations were conducted using the SOLWEIG model coupled with UMEP, allowing the analysis of solar and infrared radiation fluxes at the urban scale with high spatial resolution. The SOLWEIG model (SOLar and LongWave Environmental Irradiance Geometry) is used to evaluate urban thermal comfort by estimating radiative fluxes and the mean radiant temperature (MRT), a key indicator of pedestrian heat stress. Integrated within the UMEP plugin (Urban Multi-scale Environmental Predictor) for QGIS, it enables the simulation of radiative interactions in the built environment, taking into account urban geometry, materials, vegetation, and local meteorological conditions. Key input parameters include the radiative properties of surfaces—emissivity and albedo—defined separately for horizontal planes (ground) and vertical surfaces (walls). Three distinct scenarios were configured to represent urban materials with contrasting radiative characteristics (asphalt, resin, vegetated ground, and their associated vertical coverings). Table 1 below presents the emissivity and albedo values specific to each scenario, as well as the reference materials.

The simulated outputs include atmospheric infrared radiation (L_{down}), thermal radiation emitted by surfaces (L_{up}), incident solar radiation (K_{down}), and reflected solar radiation (K_{up}). This systematic parametrization allows isolating the impact of radiative properties on local radiative balances, providing a fundamental basis for the analysis of urban microclimates and perceived thermal conditions.

<i>Input Parameters for SOLWEIG Simulation</i>								
<i>Scenarios</i>	<i>Ground emissivity</i>	<i>Lateral emissivity</i>	<i>Ground albedo</i>	<i>Lateral albedo</i>	<i>Reference Ground Properties</i>	<i>Reference lateral Properties</i>		
<i>Scenario 1</i>	<i>0,93</i>	<i>0,89</i>	<i>0,19</i>	<i>0,23</i>	<i>Asphalt</i>	<i>Brick</i>		
<i>Scenario 2</i>	<i>0,8</i>	<i>0,79</i>	<i>0,14</i>	<i>0,13</i>	<i>Resin</i>	<i>Acrylic paint</i>		
<i>Scenario 3</i>	<i>0,74</i>	<i>0,73</i>	<i>0,11</i>	<i>0,15</i>	<i>Vegetated soil</i>	<i>Wood cladding</i>		
<i>Output Values from SOLWEIG-UMEP Simulations for the Different Scenarios</i>								
<i>Results of Radiative Simulation</i>							<i>Comfort Calculation Results</i>	
<i>Scenarios</i>	<i>Atmospheric Infrared Radiation (L_{down})</i>	<i>Thermal adiation Emitted Surfaces (L_{up})</i>	<i>Incident Solar Radiation (K_{down})</i>	<i>Reflected Solar Radiation (K_{up})</i>	<i>Mean Radiative Temperature MRT</i>	<i>Surface temperature TS</i>	<i>PET</i>	<i>GGR</i>

Table 1: Methodology for Calculating Radiative Parameters

The results include thermal comfort indicators—surface temperature (ST), mean radiant temperature (MRT), physiologically equivalent temperature (PET), and general glare rating (GGR)—computed from radiative balance calculations. The analysis was conducted for two extreme periods, Day 10 in January and Day 203 in July, using EnergyPlus Weather (EPW) meteorological data processed via the Ladybug plugin in Grasshopper and Rhino. This approach enables a quantitative assessment of the influence of the radiative properties of urban materials on local radiative fluxes and perceived thermal comfort. PET, calculated using the MEMI model (Matzarakis and Mayer, 1996) in RayMan or ENVI-met, represents the equivalent air temperature that would produce the same thermal comfort under reference conditions (no wind, 50% relative humidity, MRT = air temperature).

$$PET = T_a + f(T_{MRT}, V_{air}, RH)$$

Equation 1: The complete PET calculation is based on the formula derived from research (e.g., Matzarakis and Mayer 1996).

PET, calculated from air temperature (°C), wind speed (m/s), and relative humidity (%), assumes light metabolic activity

(~80 W/m²) and constant clothing insulation (~0.9 clo). It uses 14 °C as a reference temperature and applies empirical coefficients to modulate the effects of radiation (0.31), wind (0.017), and humidity (0.0054):

$$PET = T_a + 0.31 \times (T_{MRT} - T_a) - 0.017 \times \sqrt{V_{air}} \times (T_a - 14) + 0.0054 \times RH \times (T_a - 14)$$

Equation 2: PET simulation

The Daylight Glare Index (DGI) is a suitable metric for quantifying glare caused by natural light, particularly through windows or in open urban spaces. The formula proposed by Hopkins (1972) for calculating glare due to natural daylight in buildings is presented as follows.:

$$DGI = 10 \log (0.48 \times \sum \frac{L_{s,i}^{1.6} \times \Omega_{s,i}^{0.8}}{L_b + 0.07 \times \omega_{\omega_i}^{0.5} \times L_{\omega,i}})$$

Equation 3 : formula by (Hopkinson, R. G., 1972) for calculating the Daylight Glare Index (DGI)

Relationship between K_{up} and luminance L under the assumption of diffuse, Lambertian reflection, which is commonly assumed for urban environments:

$$GGR = \log_{10} (\sum \frac{L_{i,\Omega}}{L_b})$$

Equation 4: diffuse and Lambertian General Glare Rating (GGR) calculation approach

- L_i = luminance of source i (in cd/m²)
- Ω = apparent solid angle of source i (in steradians, sr)
- L_b = background or ambient luminance (in cd/m²)

- With: L_i = K_{up}/π (cd/m²) and $G = \frac{K_{up}}{E_{ref}}$

$$GGR = \log_{10} (\sum \frac{(K_{up}/\pi)^2 \cdot \Omega}{L_b})$$

Hence:

Equation 5: GGR formula based on source K_{up} International Commission on illumination (CIE) in technical report CIE 117 1995

Results

The evaluation of the thermo-radiative behavior of urban surfaces combines thermal emissivity and albedo. Different material scenarios were tested to explore various configurations. The figure shows the spatial distribution of downward solar flux (K_{down}) at 14:00 in winter (January, Day 10) and summer (July, Day 203). In January, fluxes are low and highly heterogeneous, with large shadowed areas due to the low solar elevation and building density. In July, K_{down} is higher and more uniform, despite local contrasts caused by the urban fabric, indicating intense insolation and an increased warming potential.

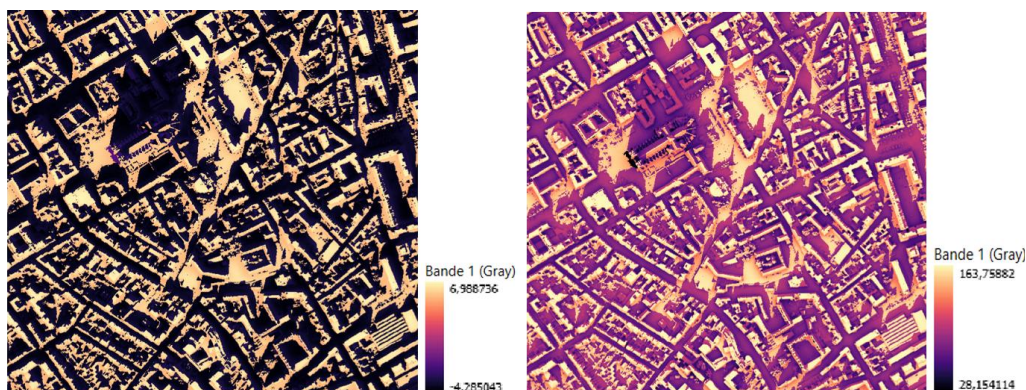


Figure 2: Mapping of Kdown Flows in W/m² in January for Day D10S on the Left and in July D203 Photos of Straight Lines at 2:00 p.m. for Scenario

In Scenario 1, the high absorptive capacity of the surfaces leads to a significant increase in their temperature, resulting in pronounced heating and an elevated risk of thermal discomfort. Scenario 2, of intermediate nature but characterized by high thermal reflectivity, shows a partial reduction of heating compared to the reference scenario but a deterioration of visual comfort due to strong glare from K_{up}. Finally, Scenario 3, consisting of surfaces with vegetation-like emissivity, exhibits the lowest temperatures and thus represents a particularly effective thermal mitigation strategy. The observed phase shift in the temporal evolution of surface temperatures among the different scenarios confirms the key role of material thermal inertia, which depends on their absorptive and reflective properties, ranging from highly absorptive materials such as asphalt or resin to surfaces with greater thermal regulation capacity, such as vegetated soils.

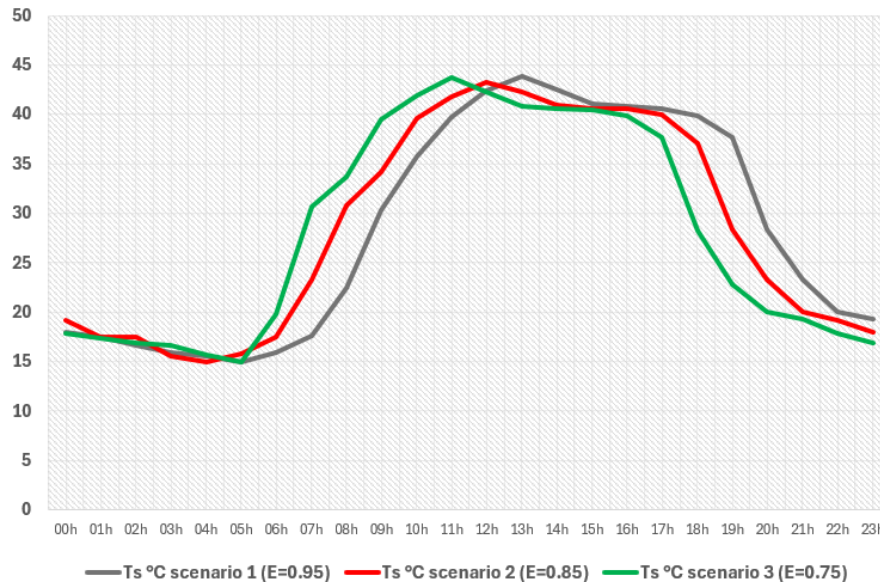


Figure 3: Evolution of Surface Temperatures Over 24 Hours Compared to Different Scenarios on Day D203

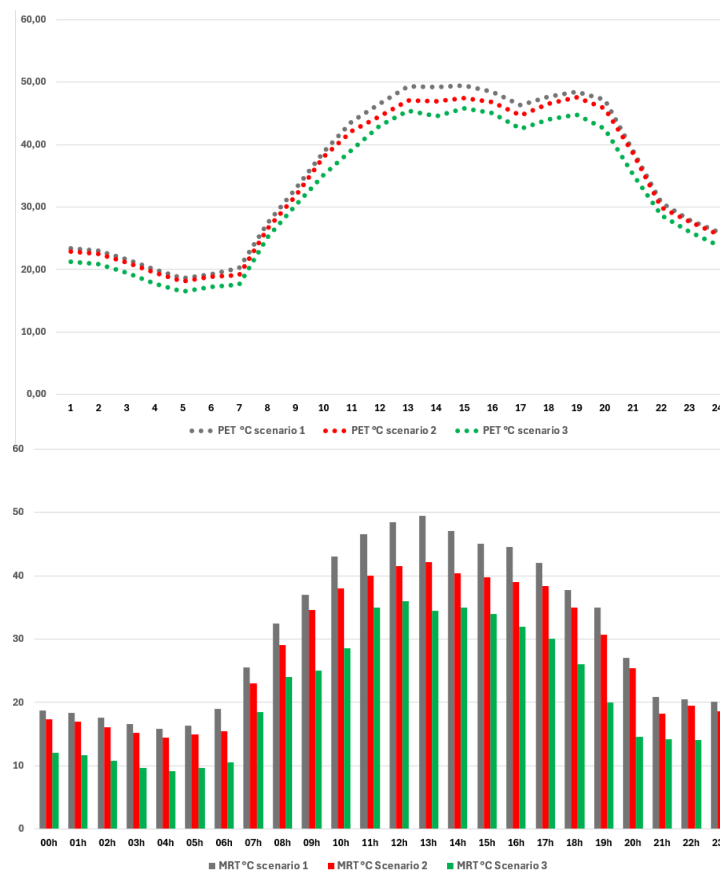


Figure 4: Evolution of Mean Radiative Temperature (MRT) With Equivalent Physiological Temperature (PET) in °C Day D203

To better understand these interactions, a comparative analysis was conducted across three distinct, representative scenarios. The reference scenario, corresponding to the most common case, serves as a baseline for comparison. Scenario 2, characterized by high surface reflectivity, allows the assessment of the impact of increased albedo on thermal and visual comfort. Finally, Scenario 3, featuring a higher vegetation coverage, aims to analyse the role of greening in modulating radiative parameters and improving overall comfort. This approach enables the identification of the most favourable conditions and provides guidance for optimizing thermal and visual comfort.

The graph presents the radiative components for the different scenarios on Day 203.

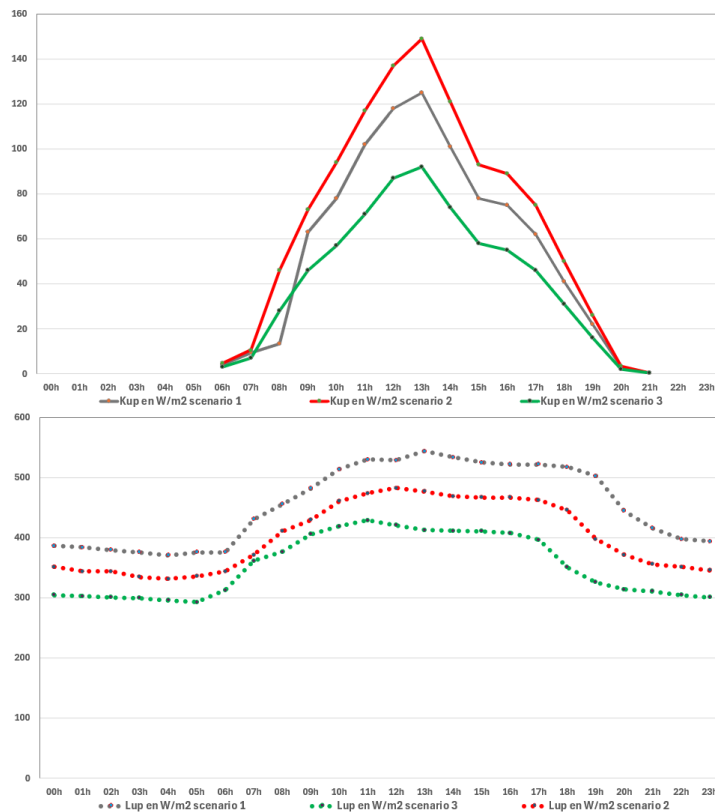


Figure 5: Analysis of Radiative Parameters for Different Scenarios Over 24 Hours (day July 17, D203)

The Global Glare Rating (GGR) index, as defined by the International Commission on Illumination (CIE) in publication 117:1995, along with the derived standards and recommendations, provides essential reference values for the assessment of visual comfort under both natural and artificial lighting. These thresholds allow for the quantification of perceived glare by the observer and are fundamental in studies of visual ergonomics, lighting design, and the analysis of solar radiation impacts, particularly in outdoor and built environments.

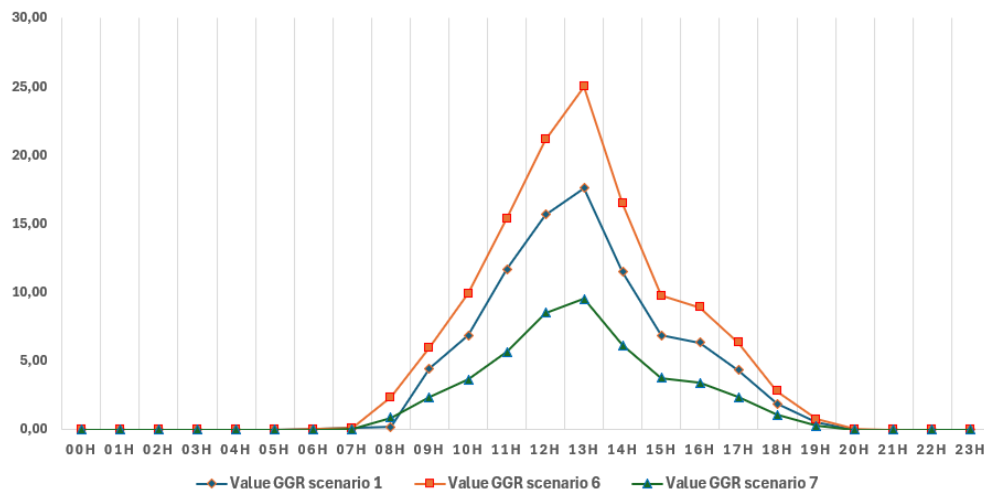


Figure 6: Analysis of Glare in Different Scenarios (GGR: General Glare Rating) (day D203)

Conclusions

The comparative analysis of the three studied scenarios highlights the decisive influence of surface radiative and thermal properties on both thermal and visual comfort. Scenario 1, corresponding to highly absorptive materials, results in the highest surface temperatures, leading to an increased risk of thermal discomfort. Scenario 2, characterized by high thermal reflectivity, partially reduces surface heating but induces strong glare, as indicated by the maximum Reflected Solar Radiation K_{up} values and the General Glare Rating "GGR" index, thereby compromising visual comfort. In contrast, Scenario 3, incorporating surfaces with vegetation-like emissivity, exhibits the lowest temperatures as well as the lowest levels of solar irradiation and glare, confirming the effectiveness of vegetation in thermal mitigation and the reduction of visual discomfort.

The observed phase shift in the temporal evolution of surface temperatures underscores the key role of material thermal inertia, which depends on their absorptive, reflective, and thermal regulation capacities. These results suggest that optimizing urban surfaces—by favouring vegetation and materials with high thermal modulation capacity—represents

an effective strategy to simultaneously enhance thermal and visual comfort in built environments.

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