ISSN 2729-7640

sciendo

ALFA ARCHITECTURE PAPERS
OF THE FACULTY OF ARCHITECTURE AND DESIGN STU
www.alfa.stuba.sk

1/2022 (Vol. 27)
DOI: 10.2478/alfa-2022-0004

Microclimatic factors in urban development: The setup of an environmental observatory at the FAD STU

Tomáš Hubinský[1]*

Ján Legény[2]

[1,2] Slovak University of Technology, Faculty of Architecture and Design, Institute of Ecological and Experimental Architecture, Bratislava, Slovakia

***Corresponding author**
E-mail: tomas.hubinsky@stuba.sk

Article information
Sent: Feb 17, 2022
Accepted: Mar 13, 2022

Abstract: The presented research focuses on energy (im)balance on both global and local scale. The main emphasis is placed on microclimatic factors directly affecting public urban spaces and related physical processes regarding the city that are closely linked to energy flows and result in the formation of Urban Heat Islands (UHIs). As they are one of the main adverse effects of human activities, the paper introduces the classification of UHIs by types, describes the basic differences between the surface energy balance of rural and urban areas, and introduces climate-sensitive urban design as one of the possible ways of mitigating the undesirable anthropogenic impact on the climate change. The authors of the article present their own research, which predominantly focuses on the development of an environmental observatory situated on the rooftop of the building of the Faculty of Architecture and Design STU in Bratislava (hereafter referred to as the FAD STU). They interpret the experimental operation of sensing probe 1 and the first results and measurement data on Global Horizontal Solar Irradiation (GHSI) and their post-processing. In addition, they describe the construction of sensing probe 2, which will provide more data on the total atmospheric precipitation, wind speed and its direction, presence of dust particles and carbon dioxide in the air, or spectral characteristics of incident and reflected solar radiation. Finally, the experimental operation of a thermal and micro- camera with fisheye lenses is described. These cameras are essential for measuring the Normalized Difference Vegetation Index (NDVI) as one of the parameters used for the assessment of vegetation vitality, which also plays a key role in the formation of the UHI effect.

Keywords: city, urban heat island, urban microclimate, physical parameters, environmental observatory, sensing probe, FAD STU

INTRODUCTION

Not only have humans been affecting biotopes, but the negative impact of anthropogenic activities results in the global climate change. As part of the main global goals to mitigate these effects, various international strategic documents on sustainability such as the *EU strategy on adaptation to climate change* (European Commission, 2013), the *European Green Deal* (European Commission, 2019), the *Climate and Environmental Emergency* (European Parliament, 2019), the *2030 climate & energy framework* (European Commission) or the *Paris Agreement* (United Nations, 2015) set out the following measures: keeping the increase in global average temperature well below 2°C compared to preindustrial levels and pursuing such efforts to limit the rise to 1.5°C, since this would significantly reduce the risks and impacts of the climate change; adoption of mitigation strategies, rapid reduction of global greenhouse gases (CO_2, CH_4, N_2O, NO_X) and aerosols among other forcings; smart integration of renewable energy sources; increasing energy efficiency; transition to the low carbon economy; development of energy storage technologies or the application of energy efficient and environmentally friendly construction and renovation of buildings. In general, cities are the man-made products of culture that act as centres of innovation, industry and labour. Currently, the share of the urban population in the world's population has reached 56%, with the expectation of an increase to 9.7 billion by 2050, with 68% of the inhabitants living in urban areas (United Nations, 2019). Although the estimates of global urban land stated in various sources vary widely from less than 1% to 3%, mainly due to different definitions of urban land (Liu, He, Zhou, Wu, 2014), cities are supposed to be responsible for most of the emissions. The *World Resources Institute Global* identified greenhouse gas emissions by sector in 2016 as follows: Energy use in buildings: 17.5% (commercial: 6.6%, residential: 10.9%), transport: 16.2%, energy use in industry: 24.2%, agriculture, forestry and land use: 18.4%, waste disposal: 3.2%; and industry: 5.2% (Ritchie, Roser, 2020). Consequently, the importance of cities will increase, while their rapid growth will bring many opportunities, apart from many challenges, to address their contribution to air pollution, rise in global surface temperature, or to different issues such as population, ageing, inclusion, safety, resilience, and sustainability. The common objective is to achieve the sustainable development introduced by the *Club of Rome* in 1972 that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development,

© 2022 Authors. This is an open access article licensed under the Creative Commons Attribution-NonCommercial-NoDerivs License (http://creativecommons.org/licenses/by-nc-nd/3.0/). Published by the Faculty of Architecture and Design, Slovak University of Technology in Bratislava, Slovakia

1987). The co-existence of living organisms (vegetation, animals and people), their communities, and the abiotic environment within cities is studied by urban ecology (Sukopp, 1998).

In turn, the relationship between the cultural environment (buildings, industry and human activities) and the biophysical habitat of ecological spheres such as the urban atmosphere, biosphere, hydrosphere, pedosphere, and lithosphere determines the characteristic processes known as *urban metabolism*, which means the transformation of materials and energy in a city (Oke, Mills, Christen, Voogt, 2017). Forman et al. calculated that 72% of global primary energy consumption is lost after conversion (Forman, Kolawole Muritala, Pardemann, Meyer, 2016), and 49.3–51.5% of global energy use would end up as waste heat in 2030, as assumed by Firth et al. (Firth, Zhang, Yang, 2019). These heat losses result mainly from (in)efficiency and have an inevitable impact on global or urban climate. Energy balance and energy efficiency are very complex issues that are closely linked with external and internal forces, and involve a variety of scales, physical parameters, distinct processes, or innovations in energy transformation.

This article focuses predominantly on microclimatic factors and their measurement, as they are crucial for city planning. The authors are of the opinion that, among many factors that come into discussion about energy flows on both global and city scale, solar energy is an *a priori* inexhaustible energy source. The general fact is that every hour the Earth is hit by about 430 quintillion Joules (430 x 10^{18} = 430 EJ) of energy from the Sun, which almost equals the total amount of 410 quintillion Joules that all humans use in a year (Nault, 2005). In this context, the advantageous aspects of solar energy such as the utilization of photovoltaics, the generating of urban structures based on the solar access principle or the energy cooperativeness of urban districts, were investigated in previous research by members of the FAD STU, namely Legény and Morgenstein (Legény, Morgenstein, 2015).

Energy (im)balance on global scale

According to Hansen et al. (Hansen, 2005), the Earth's climate system has considerable *thermal inertia* that is of critical importance, as it can influence the effects of undesirable anthropogenic climate change. In 2005, it was calculated that Earth absorbs 0.85 ± 0.15 W/m² more energy from the Sun than it emits into space (Fig. 1).

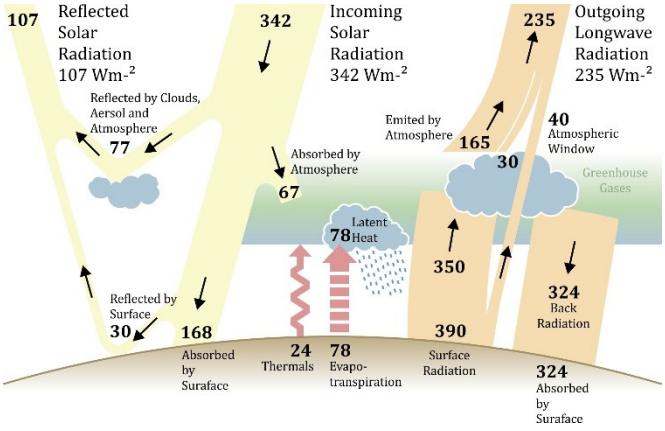


Fig. 1. The earth's annual global mean energy budget [W/m²]. (Source: Authors based on research by Kiehl and Trenberth (Kiehl, Trenberth, 1997))

This inertia delays Earth's response to climate forcings and alters global temperature. Therefore, evidence of climate change provides the opportunity to act before it becomes difficult or impossible to prevent. Nowadays, the *Earth's energy imbalance* (EEI) is relatively small and reaches the difference of 0.3% between the global mean solar radiation absorbed and the thermal infrared radiation emitted into space. About 90% of this excess energy warms the ocean, and the remainder heats the land, melts snow and ice, and warms the atmosphere. Loeb et al. (Loeb, Johnson, Thorsen, Lyman, Rose, Kato, 2021) also showed that independent satellite and *in situ* observations yield statistically indistinguishable decadal increases in EEI from mid-2005 to mid-2019 of 0.50 ± 0.47 W/m².decade. This discrepancy is caused by an increase in absorbed solar radiation associated with decreased reflection by clouds and sea ice and a decrease rate in *outgoing long-wave radiation* (OLR) caused by the increase in trace gases and water vapour (Fig. 2).

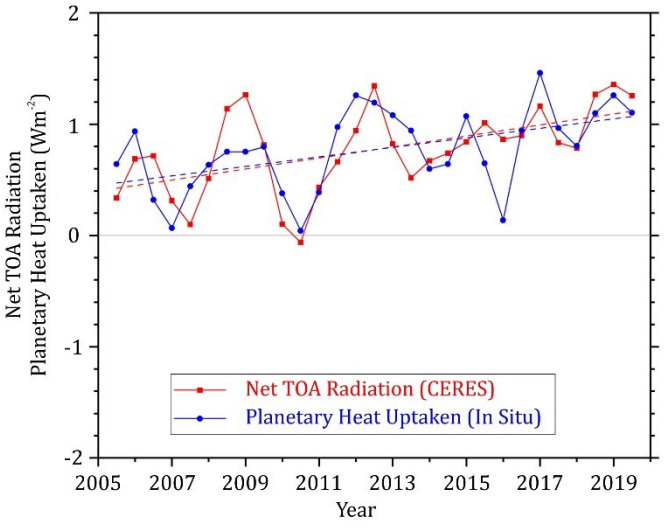


Fig. 2. Comparison of overlapping one-year estimates at 6-month intervals (Loeb, Johnson, Thorsen, Lyman, Rose, Kato, 2021). *Solid red line* - net top-of-the-atmosphere (TOA) annual energy flux from the clouds and the Earth's Radiant Energy System Energy Balanced and Filled Ed4.1 product; *Solid blue line* - an in situ observational estimate of energy uptake by Earth's climate system; *Dashed lines* - correspond to least squares linear regression fits to the data. (Source: Authors)

Energy (im)balance on local scale

Since the second half of the twentieth century, research regarding the cities and their climate has focused on various physical properties and processes, especially in terms of thermodynamics, optics, fluid mechanics, and aerodynamics of materials and their surfaces; vegetation; water bodies and water cycle; conditions in the atmosphere; solar radiation; or spatial configuration (topographic relief, geometrical characteristics of interrelated objects and spaces between them), etc. These physical properties directly affect various physical and chemical processes such as energy absorptivity, reflectivity, emissivity, thermal conductivity, transpiration, evaporation, evapotranspiration, photosynthesis, etc. With respect to meteorology, physical processes that occur on a local scale in the atmosphere near the ground, on the land surface, and in the soil are generally termed microclimatic processes. Due to the long-term consolidation of interactions between *microclimatic processes* and the relatively low rate of emerging climatic disruptions, microclimatic conditions in natural environment are rather stable and predictable in time (short or long periods) with a high degree of accuracy. In the Anthropocene epoch characterized by human activities with dominant influence on disruptions in the natural flow of energy and matter, the climate has become highly unpredictable on all spatial-temporal scales. Thus, urban climate is one of the most evident examples of inadvertent climate modification caused by humans (Oke, Mills, Christen, Voogt, 2017). Human activities are there-

fore considered the dominant microclimatic processes within the city and are directly linked to microclimate changes.

Urban Heat Island effect

One of the main negative modifications of urban microclimate involves the temperature differences arising from differences in urban and rural cooling and warming rates at the surface, in the substrate, and in the air. Such temperature of an area, volume, or region that is higher than that of non-urban surroundings is referred to as the *urban heat island* effect (UHI), first observed and documented by Luke Howard in 1833 around London, England (Stewart, 2011). An urban heat island simply refers to the characteristic warmth of a town or city. Many papers comprehensively describing main characteristics of the UHI effect in the urban climate have already been written, such as those by Chandler (1976), Landsberg (1981), Oke (1982), Arnfield (1998), Voogt (2002), Weng (2009), Huang and Lu (2018), etc. The UHI effect has an impact on increased energy consumption for cooling the buildings and reduces the residential quality of the urban environment and its public spaces (especially through overheating, increased levels of pollutants, ozone, emissions, and smog), with a direct impact on population health, economy, infrastructure, or urban safety as a consequence of the increased incidence of extreme weather conditions such as storms, floods, droughts, etc. According to Hofierka, mitigating urban heat islands requires understanding the interaction between solar radiation and urban surfaces, as well as the appropriate tools to simulate urban development and management scenarios (Hofierka, Zlocha, 2012).

Within the vertical division of the urban environment and the difference in temperature between urban areas and their non-urban (rural) surroundings, the UHI has been classified into 4 types (Oke, 1995; 2017), (Fig. 3):

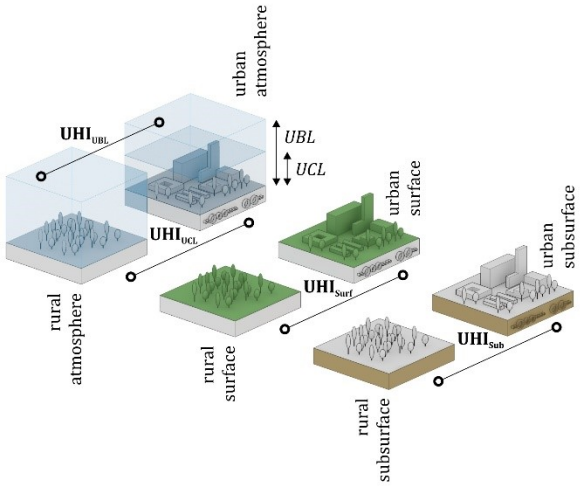


Fig. 3. Representation of temperature differences describing 4 types of UHI: UHI_{Sub}, UHI_{Surf}, UHI_{UCL}, UHI_{UBL}. (Source: Authors, with modifications based on Oke, 2017 (Oke, Mills, Christen, Voogt, 2017))

• ***Subsurface urban heat island (UHIS$_{ub}$)***: differences between temperature patterns in the ground under the city;
• ***Surface urban heat island (UHI$_{Surf}$)***: temperature differences at the interface of the outdoor atmosphere with the solid materials of the city and the equivalent rural air-to-the-ground interface;
• ***Canopy layer urban heat island (UHI$_{UCL}$)***: difference between the temperature of the air contained in the urban canopy layer (UCL), the layer between the urban surface and roof level (the exterior UCL), and the corresponding height in the near-surface layer of the countryside;
• ***Boundary layer urban heat island (UHI$_{UBL}$)***: difference between the temperature of the air in the layer between the top of the UCL and the top of the urban boundary layer (UBL), and that at similar elevations in the atmospheric boundary layer (ABL) of the surrounding rural region.

Regarding the UHI formation, T. R. Oke considers the *surface energy balance* (SEB) to be a statement of the conservation of energy which is applicable to surfaces and volumes at all spatial and temporal scales as the fundamental starting point for understanding and predicting surface microclimates and climates of the *atmospheric boundary layer* (ABL). In urban systems, the energy balance is observed on individual facets (such as roofs, walls, roads, etc.), urban elements immersed in the urban atmosphere (like human bodies, buildings), or within the entire surface-atmosphere interface, or with regard to selected layers of the atmosphere (Oke, 1987). Thus, the SEB determines heat fluxes resulting from the radiative, aerodynamic, thermal, and moisture properties of the constituent surfaces and the state of the ABL.

The surface energy balance of a *rural area* (Fig. 4a) is calculated as follows:

$$Q^* = Q_G + Q_H + Q_E \qquad [W/m^2]$$

In contrast, the surface energy balance of an *urban area* (Fig. 4b) is described by the equation:

$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S + \Delta Q_A \qquad [W/m^2]$$

• ***Q*** [W/m²] - Net all-wave radiation flux density*
• ***Q$_G$** [W/m²] - Substrate heat flux density* (ground heat flux density that transfers sensible heat downward into the substrate by conduction)
• ***Q$_H$** [W/m²] - Turbulent sensible heat flux density* (sensible heat flux density from the surface upward into the atmosphere)
• ***Q$_E$** [W/m²] – Turbulent latent heat flux density* (latent heat flux density involves exchanges of energy between the surface and the atmosphere)
• ***Q$_F$** [W/m²] - Anthropogenic heat flux density* (heat emitted from human activities such as housing, work and transport)
• ***ΔQ$_S$** [J; W/m², W/m³] - Net heat storage; rate per unit volume or per unit horizontal area* (heat accumulated by city structures, trees, surface and air)
• ***ΔQ$_A$** [J; W/m², W/m³] - Net energy (sensible and latent) advection; rate per unit volume or per unit horizontal area* (energy added or removed from the observed volume by wind: $\Delta Q_A = Q_{in} - Q_{out}$)

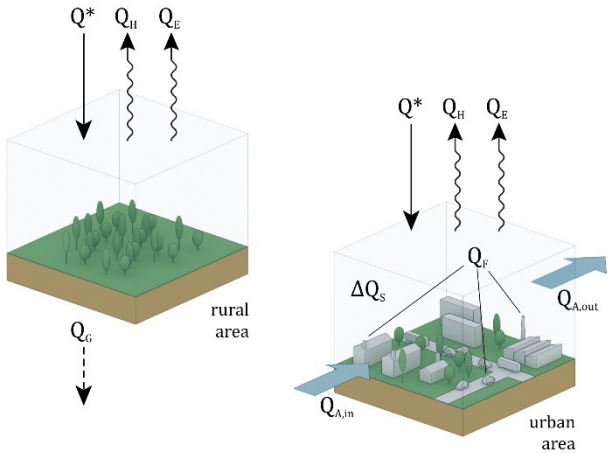


Fig. 4. Comparison of heat flux exchange within rural and urban areas. (Source: Authors, with modifications based on Oke, 1987)

Climate-sensitive urban design

Compared to basic research, the level to which knowledge is implemented in practice in the field of urban microclimate is deficient. Lowry (Lowry, 1988) considers the availability of meteorological data for urban planners crucial and emphasizes the need for their collection and further analysis and interpretation using new advanced tools. Advances in data science have made it possible to process a large number of data (Big Data) from diverse sources (even with different levels of accuracy and spatial detail) using statistical analysis methods, and to thus gain relevant sources of information that complement the existing ground-based and remote sensing infrastructure. For example, civil flight tracks, especially take-offs and landings that involve the crossing of the vertical layers of the atmosphere above the earth's surface (Moninger, Mamrosh, Pauley, 2003), private weather stations (Weather Underground), mobile smart devices simultaneously recording environmental data (ambient temperature, atmospheric pressure and noise level), or personal data devices on user vitality through Health Apps (Niforatos, Vourvopoulos, Langheinrich, 2017) are used in data crowdsourcing. The increasing number of meteosensors should result in higher data quality, their spatial-temporal density, and shorter response time, with the expected accompanying refinement of forecasting models, improved crisis management, and provision of tools for the retrospective assessment of environmental strategies within the city. The main objective of *Climate-sensitive Urban Design* (CSUD) is a city that uses resources efficiently in terms of sustainability in order to protect its residents and traffic from severe weather phenomena. This approach to designing a resilient city system uses networking, technologies, and city process management through compactness, high density, diversity of land use, refurbishment, short-distance accessibility, and community life-supporting measures to prevent the occupation of rural surroundings.

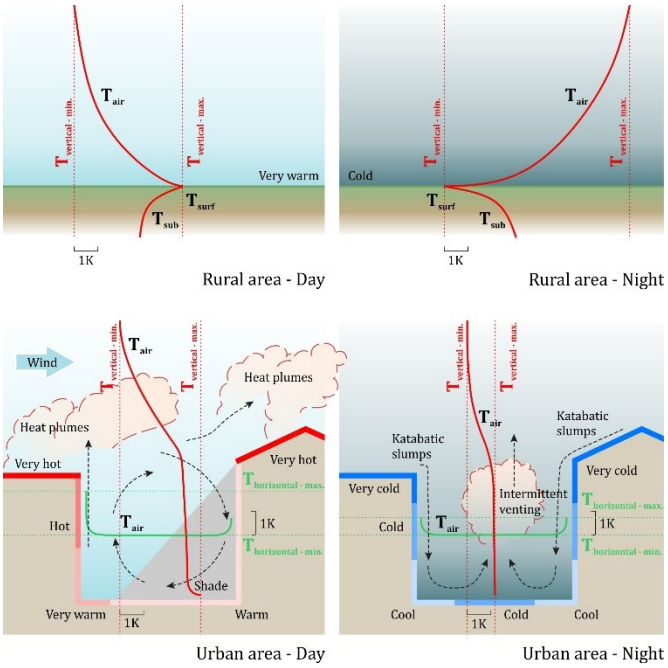


Fig. 5. Schematic representation of a typical diurnal sequence of vertical and horizontal profiles of air temperature in the near-surface layer of an open rural and urban area in the daytime and at night. Compared to the rural environment, the complexity of microclimatic processes in the heterogeneous city environment is significantly higher. It is manifested through the course of temperatures in both the vertical and horizontal plane. The temperature in the horizontal plane in a rural environment is homogeneous with increasing height. Comprehension of these processes is crucial for climate-sensitive urban design. (Source: Authors, with modifications based on Oke, 2017 (Oke, Mills, Christen, Voogt, 2017))

Furthermore, this concept is closely related to another concept termed *Positive Energy Districts* (PEDs) that was created to facilitate the energy transition and contribute to climate neutrality through energy efficiency and net zero energy balance (Derkenbaeva, Vega, Hofstede, van Leeuwen, 2022). The current research conducted at the FAD STU aims to contribute to these sustainable strategies and city management (Fig. 5).

METHODS AND RESULTS

Despite the unparalleled advantage the satellite images provide with regard to the exploration of the UHI_{Surf}, remote sensing in a heterogeneous city environment is about to reach its limits, and its accuracy is affected by many factors such as the observation height, viewing angle, resolution of sensor, atmospheric corrections, surface emissivity, anisotropy, etc. In terms of observations of urban microclimate and the UHI effect, the *Land Surface Temperature* (LST) derived from radiometric thermal images of remote sensing is only partial information quantifying the UHI_{Surf}. A great research challenge is to define the direct, non-empirical interrelationship between UHI_{Surf} and UHI_{UBL} (Voogt, Oke, 2003; Zhou, Xiao, Bonafoni, Berger, Deilami, Zhou, Frolking, Yao, Qiao, Sobrino, 2019) and to apply satellite-derived LSTs directly in air UHI detection, attribution, and modelling (Weng, 2009). In this respect, in addition to remote sensing, it is necessary to perform terrestrial observations, which is fully in accordance with the intention of the authors to build an environmental observatory on the grounds of the FAD STU. The authors have been conducting long-term measurements of the *Global Horizontal Solar Irradiation* (GHSI) at two-minute intervals that began on March 21, 2021 (spring equinox). For this purpose, the first experimental measuring set consisting of a pair of pyranometers (EKO instruments MS-40 that create an albedometer) with a two-channel data logger was installed on the roof of the FAD STU (Fig. 6). Regular measurements were preceded by trial measurements.



Fig. 6. Set of two pyranometers and a data logger on a roof. (Photo: Authors)

The output of *in-site* measurements from this gauger with the data logger is in plain text format that is processed in MS Excel using the *Visual Basic for Applications* (VBA) programming interface. GHSI values are arranged in two-minute, daily, weekly, monthly and annual data sets with average 20-minute daily performances. These data are supplemented with values from the celestial mechanics equations (Global Monitoring Laboratory) based on the geographical longitude of a location, such as the sunrise and sunset times, sunshine duration, the solar altitude and azimuth (Fig. 7, 8). Data sets are then used for analyses and calculations in prediction models, and, in the long term, they provide a basis for observing the year-on-year development of the GHSI as well.

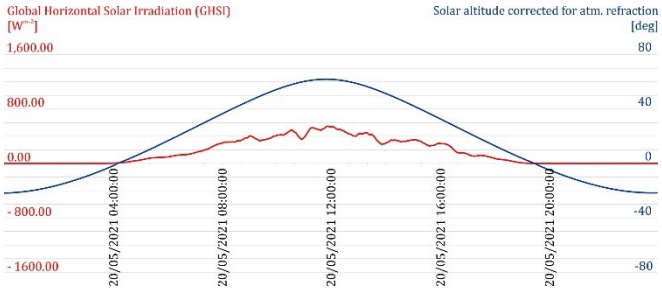


Fig. 7. Average GHSI behaviour in week 20, 2021. (Source: Authors)

Explanatory notes:

— average 20-minute GHSI per week [W/m²];

— solar altitude [deg] corrected for atmospheric refraction on the midday of the week

GHSI performance per week: 27.550 [kWh/m²]

Sunlight duration per week: 6469.461 [minutes]

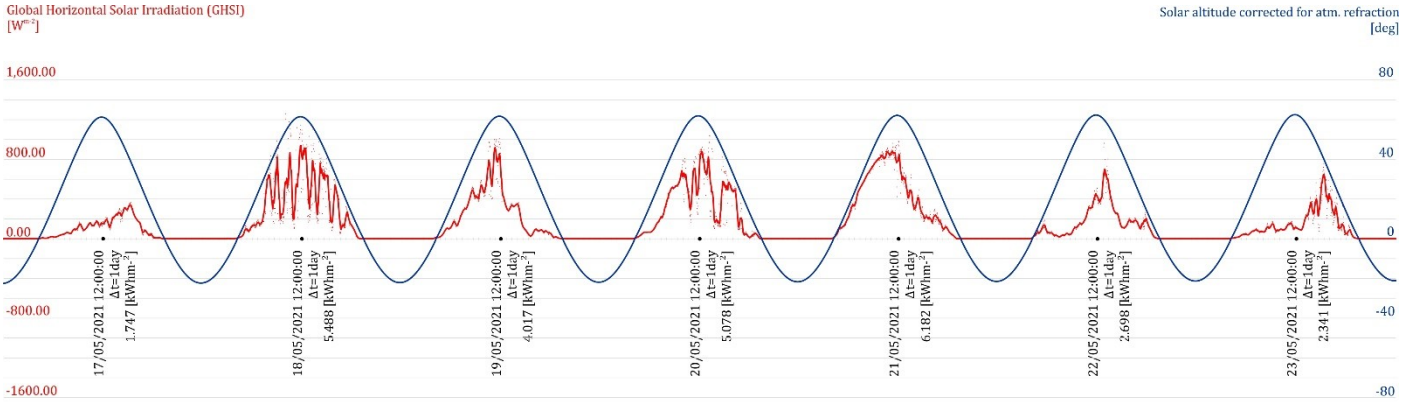


Fig. 8. Daily GHSI behaviour in week 20, 2021. (Source: Authors)

Explanatory notes:

.... GHSI [W/m²] measured in a 2-minute interval / — 20-minute mean GHSI [W/m²] / ● Daily performance [kWh/m²]

— Solar altitude [deg] corrected for atmospheric refraction

The authors plan to equip the pyranometers with shielding so that diffuse and direct or peculiar components of global and radiation can be measured (Fig. 9a), and with infrared cut-off filters. Furthermore, the filters will reflect or block UV and visible light while passing near-infrared wavelengths (Fig. 9b). Such refined data will provide a basis for better understanding of the microclimate processes in the city associated with solar energy and material properties.

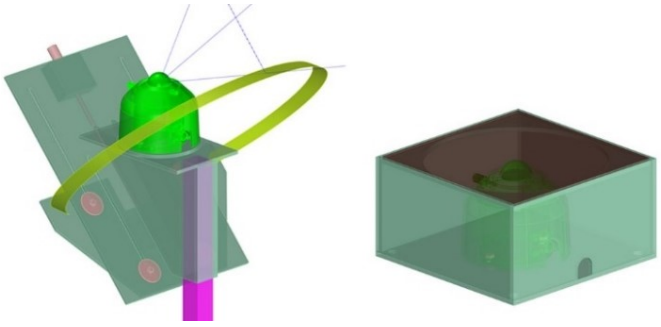


Fig. 9. Proposed shielding and infrared cut-off filter for applied pyranometers. (Source: Authors)

According to the law of conservation of energy and the equation for calorimetry that describes heat exchange, the temperature increase ratio and the GHSI ratio between the seasons should be equal. The disparity resulting from the measured data suggests that under real conditions there is no equilibrium of the energy balance in daily cycles, which is caused by the inertia of heat in the environment (Tab. 1). This property of the environment is inherent, but in the human-influenced habitat of cities, the inertia of heat is manifested through positive temperature differences to a greater extent. Admittedly, this partial research finding is largely simplified compared to the real degree of complexity of environmental climatic inter-actions.

Tab. 1. Measurement data on GHSI, sunshine duration, and increase in average temperature over seasons on the FAD STU rooftop. (Source: Authors)

Season	**GHSI** [kWh/m²]	**Sunshine duration** [h]	**Temperature increase** [°C]
Spring	447 *(100%)*	1351 *(100%)*	6.4 *(100%)*
Summer	528 *(118%)*	1355 *(100,3%)*	11.7 *(183%)*

Experimental sensing probe 1

In parallel with the GHSI measurements, the operation of vertical sensing probe 1 was launched (Fig. 10). The issues of urban microclimate and the mitigation of UHI effects through architectural and urban planning tools are closely related to the interaction between city surfaces and its surroundings. Therefore, the authors started to measure fundamental physical parameters in the vertical direction such as temperature, relative air humidity, direct and reflected solar radiation, the presence of water in the substrate, the presence of water mist, the intensity of direct or reflected sunlight on a surface, and atmospheric pressure. Besides the structural elements forming the support, this experimental vertical sensing probe includes sensors monitoring the above-mentioned parameters and is also equipped with an added controller, clock, and recording medium, which are interconnected and create a measuring set with a data logger constructed with the wiring and processing method using the Arduino platform. As in the previous GHSI case, the gathered data were processed via MS Excel and VBA (Fig. 11). The authors evaluated the possibilities of these programs as limited and consider using the *Matlab* platform for future data processing.



Fig. 10. Experimental vertical sensing probe 1. (Photo: Authors)

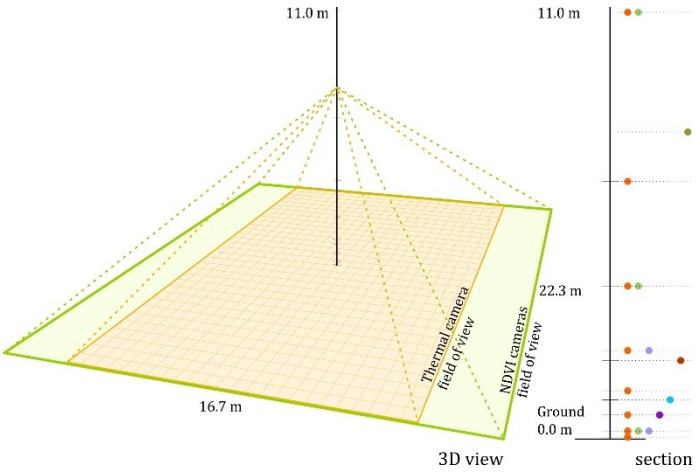


Fig. 12. Scheme of sensing probe 2 with a set of various types of sensors. (Source: Authors)

Explanation notes:

- *Thermal sensor (accuracy ±0.1 °C)*
- *Relative humidity sensor (accuracy ±1.5% RH)*
- *IR thermal sensor (surface brightness temperature, accuracy ±0.2 °C)*
- *Optical sensors of incident and reflected solar radiation (spectrometer – 8 wave bands of visible light and NIR; luxmeter, accuracy ±0.1 lx; UV sensor), environmental sensors (barometer, anemometer, dust laser sensor, CO_2 IR sensor)*
- *Environmental sensors (NDVI – three 5Mpx cameras with 110°FOV lens and IR band cut filter (740 nm), Deep Red band pass filter (650 – 680 nm), Blue band pass filter (425 – 495 nm); stereographic capturing of sky, cloudiness and Sky View Factor (ψ_{sky}) with two 5Mpx cameras with fish eye lenses; thermal camera, 768 px, 110° FOV, (accuracy ±0.5 / ±2.0 °C for capturing surface brightness temperature)*

Sensing probe 2 – under construction

The measurement method and the output using experimental vertical sensing probe 1 have been verified in trial operation and have been assessed as suitable for future research and development. Therefore, the higher sensing probe 2 (with the total height of 11m) is currently under construction and should provide data from an area of approximately 12 x 22 m. The set of sensors mounted on probe 1 will also be expanded. The authors anticipate the measurement of the total atmospheric precipitation, wind speed and its direction, presence of dust particles and carbon dioxide in the air, or spectral characteristics of incident and reflected solar irradiation. Furthermore, the cloudiness and the Sky View Factor (ψ_{sky}) will be evaluated using cameras facing the sky (Fig. 12).

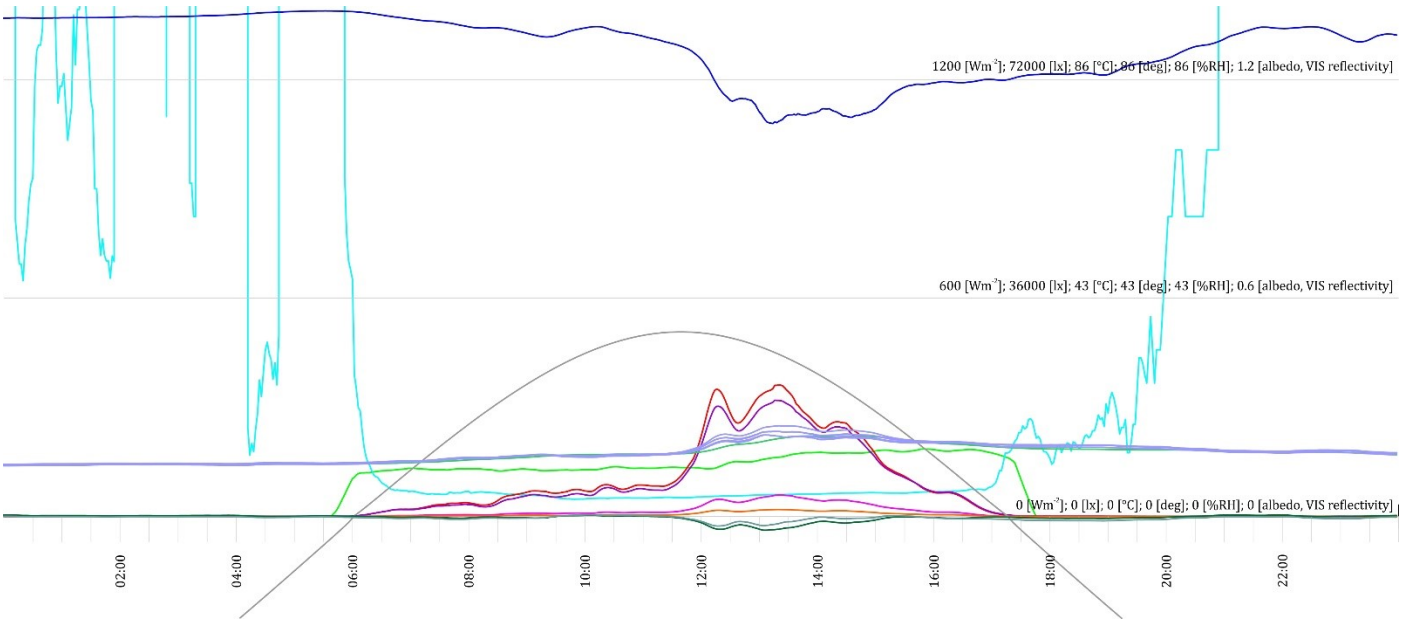


Fig. 11. Daily behaviour of specific physical parameters on November 7, 2021, recorded by sensing probe 1. (Photo: Authors)

Explanatory notes:

Air temperature above ground at different levels [°C]; Surface temperature [°C]; Temperature difference between surface and air at 0.15m [°C]; Temperature difference between surface and air at 1.2m height [°C]; Incident GHSI [W/m²]; Reflected solar irradiation on horizontal plane [W/m²]; Surface albedo [-]; Incident light intensity on horizontal plane [lx]; Reflected light intensity on horizontal plane [lx]; Light reflectivity [-]; Relative humidity [RH%]; Solar altitude [deg]

Cameras facing the surface will detect the Normalized Difference Vegetation Index (NDVI) introduced by Rouse et al. (Kuska, Behmann, Mahlein, 2018). It is based on the optical properties of healthy and treated leaves distinguished in the RGB image. Vital plants largely reflect infrared radiation. Chlorophyll, among other photo pig-ments, is responsible for leaf colour and is important in the conversion of energy from light through photosynthesis. It ab-sorbs light of the characteristic wavelength - chlorophyll A (dark red light / 640 – 680 nm), chlorophyll B (blue light / 425 – 495 nm). NDVI is given by the ratio of NearInfraRed–Red and Near-InfraRed+Red light and reaches values in the range of -1 to 1. This index is used not only in remote sensing to assess the vitality of greenery, but also to categorize land use (vegetation, water bodies, soil and built-up areas). Surfaces without vegetation will be scanned by sensing probe 2 using an IR filter cam-era and their response to IR radiation will be evaluated. Currently, the authors are testing the functionality of the NDVI sensors (Fig. 13).

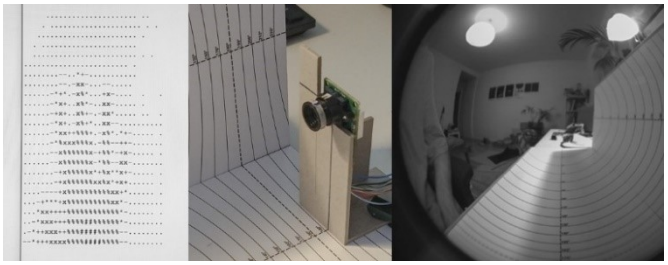


Fig. 13. Testing the functionality of the thermal- and micro-camera with fisheye lenses. (Source: Authors)

DISCUSSION AND CONLUSIONS

The deterioration of the environment and the threat of the climate change are real and some action is needed. The main attribute of contemporary architecture shall be sustainability, and the cities of the future must be resilient, safe, healthy, sustainable, and human-centric while preserving nature, in-deed. The pursuit of climate-sensitive urban design and positive energy districts are possible responses to these human challenges. The unprecedented development of new technologies enables the acquisition and processing of big data to influence the microclimate of cities.

There are still some specific issues that researchers should address. The first is the development and creation of data prediction models, where the current trend is to increase the complexity of the evaluated microclimatic factors in spatial-temporal detail. Such predictive models and simulations (e.g. in Envi-met 4.1 program) help architects and urban planners understand the interaction of microclimatic factors with the surroundings and allow them to verify the expected benefits of solutions during the design phase. The second is the critical retrospective evaluation of implemented solutions exposed to real conditions not only at the level of architectural and urban design, but also regarding engineering and technical solutions, such as the material composition of surfaces (Holečka, Jamnický, Krajčík, Rabenseifer, 2021). This approach supports the continuation of the evolution of engineering design. The third is the increase of the use of quantifiable parameters to rate the impact of individual and interacting microclimatic factors and to facilitate complex decision-making within the design process. For example, the *Solar Reflectance Index* (SRI) generally used by the *Leadership in Energy and Environmental Design* (LEED) certification is a derived parameter that takes into account the solar reflectivity and emissivity of surfaces in accordance with the *Standard Terminology of Solar Energy Conversion* (ASTM E 772) and the *Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces* (ASTM E 1980).

The creation of an environmental observatory on the grounds of the FAD STU whose operation was experimentally verified by sensing probe 1 along with the future location of sensing probes no. 2 in selected public urban spaces creates a prerequisite for conducting further research in the field of microclimatic factors affecting urban development. Based on the review of sources, the authors, together with colleagues and research partners from the Pavol Jozef Šafárik University, the Institute of Geography of the Faculty of Science in Košice, Slovakia, are currently specifying the albedo values of materials usually applied in buildings and urban spaces that affect the reflection and absorption of incident solar energy. These values will refine the modelling of solar radiation in the city areas using the GIS software and the *v.sun* and *r.sun* models developed by Hofierka et al. (Hofierka, Zlocha, 2012). For the presentation of the high-resolution surface temperatures modelling in the city, the *Tangible Landscape* system will be used. This interactive tool will be useful for architects and designers, enabling them to project specific digital layers from 3D GIS not only regarding solar energy.

Acknowledgements

The research was funded by the Slovak Research and Development Agency (APVV) under contract No. APVV-18-0044: Solar potential in urban areas and its application to the Smart City concept.

References

Arnfield, A. J. (1998) "Micro- and Mesoclimatology. Progress in Physical Geograph", Earth and Environment, 22(1), pp. 103–113. https://doi.org/10.1177/030913339802200106

Chandler, T. J. (1976) "The climate of towns. The Climate of the BritishIsles", London: Longman, pp. 307-329. ISBN-13: 978-0582485587

Derkenbaeva, E., Vega, S. H., Hofstede, G. J., van Leeuwen, E. (2022) "Positive energy districts: Mainstreaming energy transition in urban areas", Renewable and Sustainable Energy Reviews, 153(2022), 111782 https://doi.org/10.1016/j.rser.2021.111782

European Commission (2013) "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions An EU Strategy on adaptation to climate change, COM/2013/0216". [online] Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52013DC0216&from=SK [Accessed: 9 January 2022]

European Commission (2019) "Communication from the Commission The European Green Deal, COM/2019/640 final". [online] Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN [Accessed: 28 December 2021]

European Commission "2030 climate & energy framework", [online] Available at: https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2030-climate-energy-framework_en [Accessed: 30 November 2021]

European Parliament (2019) "Climate and Environmental Emergency - 2019/2930 (RSP)". [online] Available at: http://www.europarl.europa.eu/doceo/document/TA-9-2019-0078_EN.html [Accessed: 30 November 2021]

Firth, A., Zhang, B., Yang, A. (2019) "Quantification of global waste heat and its environmental effects", Applied Energy. 235(2019): 1314-1334.

Forman, C., Kolawole Muritala, I., Pardemann, R., Meyer, B. (2016) "Estimating the global waste heat potential", Renewable and Sustainable Energy Reviews. 57(2016), pp. 1568-1579. https://doi.org/10.1016/j.rser.2015.12.192

Global Monitoring Laboratory "Solar Calculation Details" [online] Available at: https://gml.noaa.gov/grad/solcalc/calcdetails.html [Accessed: 28 December 2021]

Hansen, J., et al. (2005) "Earth's Energy Imbalance: Confirmation and Implications", Science 308(5727), pp. 1431-5. https://doi.org/10.1126/science.1110252

Hofierka, J., Zlocha, M. (2012) "A new 3D Solar Radiation Model for 3D City Models", Transactions in GIS. 16(5), pp. 681–690. https://doi.org/10.1111/j.1467-9671.2012.01337.x

Holečka, M., Jamnický, M., Krajčík, M., Rabenseifer, R. (2021) „Extensive Roof Greenery as a Response to Heat Islands: Some Problems", Slovak Journal of Civil Engineering, 29(4), pp. 9-12. https://doi.org/10.2478/sjce-2021-0022

Huang, Q. and Lu, Y. (2018) "Urban heat island research from 1991 to 2015: a bibliometric analysis", Theoretical and Applied Climatology, 131(2018), pp. 1055–1067. https://doi.org/10.1007/s00704-016-2025-1

Kiehl, J.T., Trenberth, K, E. (1997) "Earth's Annual Global Mean Energy Budget", Bulletin of the American Meteorological Society. 78(2), pp. 197-208. https://doi.org/10.1175/1520-0477(1997)078<0197:EAGMEB>2.0.CO;2

Kuska, M., Behmann, J. and Mahlein, A. (2018) "Potential of hyperspectral imaging to detect and identify the impact of chemical warfare compounds on plant tissue", Pure and Applied Chemistry, 90(10), pp. 1615-1624. https://doi.org/10.1515/pac-2018-0102

Landsberg, H. E. (1981) "The Urban Climate", Volume 28, 1st Edition. International Geophysics Series, pp. 1-277. ISBN: 9780080924199

Legény, J., Morgenstein, P. (2015) "Solárna stratégia udržateľného mesta (Solar Strategy of a Sustainable City)", Bratislava: Vydavateľstvo STU. ISBN 9788022743662

Liu, Z., He, CH., Zhou, Y., Wu, J. (2014) "How much of the world's land has been urbanized, really? A hierarchical framework for avoiding confusion", Landscape Ecology. 29(2014), pp. 763–771. https://doi.org/10.1007/s10980-014-0034-y

Loeb, N. G., Johnson, G. C., Thorsen, T. J., Lyman, J. M., Rose, F. G., & Kato, S. (2021) "Satellite and ocean data reveal marked increase in Earth's heating rate", Geophysical Research Letters, 48, e2021GL093047. https://doi.org/10.1029/2021GL093047

Lowry, W.P. (1988) "Atmospheric ecology for designers and planners", Peavine Publications; First Paperback Edition (January 1, 1988). ISBN-13: 978-0929002071

Moninger, W. R., Mamrosh, R. D., Pauley, P. M. (2003) "Automated Meteorological Reports from Commercial Aircraft", Bulletin, American Meteorological Society, 84(2), pp. 203-216. https://doi.org/10.1175/BAMS-84-2-203

Nault, R. M. (2005) "Basic Research Needs for Solar Energy Utilization. Report on the Basic Energy Sciences Workshop on Solar Energy Utilization", Argonne National Laboratory, Lemont, Illinois, USA. [online] Available at: https://science.osti.gov/~/media/bes/pdf/reports/files/Basic_Research_Needs_for_Solar_Energy_Utilization_rpt.pdf [Accessed: 2 February 2022]

Niforatos, E., Vourvopoulos, A., Langheinrich, M. (2017) "Understanding the potential of human–machine crowdsourcing for weather data", International Journal of Human-Computer Studies, 102(2017), pp. 54-68. https://doi.org/10.1016/j.ijhcs.2016.10.002

Oke T.R. (1995) "The Heat Island of the Urban Boundary Layer: Characteristics, Causes and Effects", In: Cermak J.E., Davenport A.G., Plate E.J., Viegas D.X. (eds) "Wind Climate in Cities", NATO ASI Series (Series E: Applied Sciences), Vol 277, Springer, Dordrecht. https://doi.org/10.1007/978-94-017-3686-2_5

Oke T.R. (1995) "The Heat Island of the Urban Boundary Layer: Characteristics, Causes and Effects", In: Cermak J.E., Davenport A.G., Plate E.J., Viegas D.X. (eds): Wind Climate in Cities. NATO ASI Series (Series E: Applied Sciences), Vol 277, Springer, Dordrecht, pp. 156. https://doi.org/10.1007/978-94-017-3686-2_5

Oke, T. R (1987) "Boundary Layer Climates", UK: Psychology Press, 435 p. ISBN 9780415043199

Oke, T. R. (1982) "The energetic basis of the urban heat island", Quarterly Journal of the Royal Meteorological Society, 108(455), pp. 1-24.

Oke, T. R., Mills, G., Christen, A., Voogt, J. A. (2017) "Urban Climates", Cambridge: Cambridge University Press. ISBN 9780521849500. https://doi.org/10.1017/9781139016476

Ritchie, H., Roser, M. (2020) "CO_2 and Greenhouse Gas Emissions" [online] Available at: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions [Accessed: 10 January 2022]

Stewart, I.D. (2011) "A systematic review and scientific critique of methodology in modern urban heat island literature", International Journal of Climatology. Volume 31, Issue (2), pp. 200-217. https://doi.org/10.1002/joc.2141

Sukopp, H. (1998) "Urban Ecology - Scientific and Practical Aspects", In: Breuste, J., H. Feldmann, and O. Uhlmann, (eds.). Urban Ecology. Berlin: Springer, pp. 3-16.

United Nations (2015) "Paris Agreement" [online] Available at: https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf [Accessed: 29 December 2021]

United Nations, Department of Economic and Social Affairs, Population Division (2019) "World Population Prospects 2019: Highlights (ST/ESA/SER.A/423)". ISBN: 978-92-1-148316-1

Voogt, J. A. (2002) "Urban Heat Island", In: Munn, T. (eds) Encyclopedia of Global Environmental Change, Wiley, Chichester, pp. 660-666. ISBN 0-471-97796-9

Voogt, J. A., Oke, T. R. (2003) "Thermal remote sensing of urban climates", Remote Sensing of Environment, 86(3), pp. 370-384. https://doi.org/10.1016/S0034-4257(03)00079-8

Weather Underground "Personal Weather Station Network" [online] Available at: https://www.wunderground.com/pws/overview [Accessed: 28 December 2021]

Weng, Q. (2009) "Thermal infrared remote sensing for urban climate and environmental studies: Methods, applications, and trends", ISPRS Journal of Photogrammetry & Remote Sensing, 64(4), pp. 335 - 344. https://doi.org/10.1016/j.isprsjprs.2009.03.007

Weng, Q. (2009) "Thermal infrared remote sensing for urban climate and environmental studies: Methods, applications, and trends", ISPRS Journal of Photogrammetry and Remote Sensing, 64(4), pp. 335–344. https://doi.org/10.1016/j.isprsjprs.2009.03.007

World Commission on Environment and Development (1987) "Our Common Future", Oxford: Oxford University Press, 383 p. ISBN 019282080X

Zhou, D,. Xiao, J., Bonafoni, S., Berger, C., Deilami, K., Zhou, Y., Frolking, S,. Yao, R., Qiao, Z., Sobrino, J.A. (2019) "Satellite Remote Sensing of Surface Urban Heat Islands", Progress, Challenges, and Perspectives. Remote Sensing, 11(1), 48. https://doi.org/10.3390/rs11010048