parkovi

spona gradova i prirode

PARKS – A LINK BETWEEN CITIES AND NATURE

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Klimatsko značenje parkova u urbanim područjima

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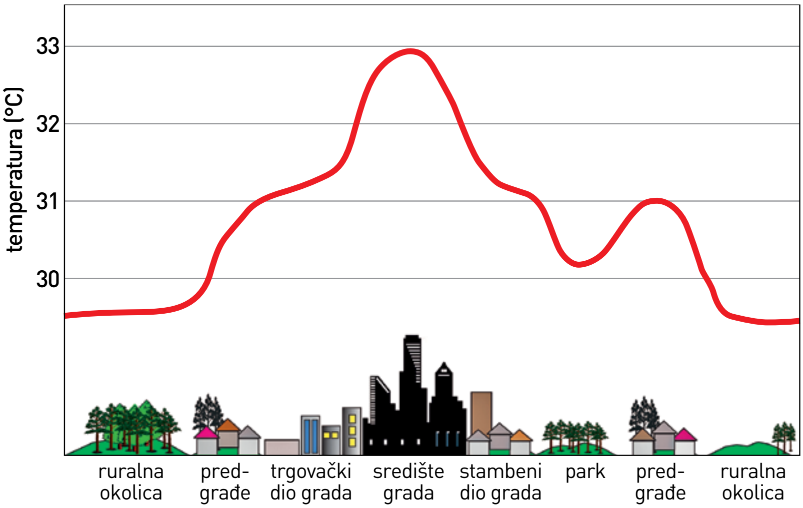
Toplinski otok grada i parkovi

Gradovi modificiraju lokalnu klimu područja u kojem se nalaze, što najviše do izražaja dolazi kroz fenomen koji se naziva toplinski otok grada (eng. urban heat island – UHI), a očituje se u višoj temperaturi zraka u gradu u odnosu na njegovu ruralnu okolicu (Oke i dr., 2017). Osnovni uzrok te pojave su umjetni materijali (asfalt, beton i drugi) od kojih su izgrađeni gradovi te oni danju apsorbiraju više Sunčeve kratkovalne radijacije nego prirodna podloga u ruralnoj okolici grada. Ta akumulirana toplina zagrijava grad, što najviše do izražaja dolazi tijekom noći i zimi, kada je ohlađivanje dugovalnom radijacijom najjače. Intenzitet toplinskog otoka grada ovisi o veličini grada, gustoći građevina, njegovu smještaju, sinoptičkoj situaciji, dobu dana i godine te drugim čimbenicima. Toplinski otok grada ima izravan učinak na život ljudi u gradovima te utječe na kvalitetu života njihovih stanovnika, što se najviše očituje kroz negativne posljedice – visoke dnevne i noćne temperature zraka, onečišćenje zraka, povećanu potrošnju energije, ugrozu ljudskog zdravlja, smanjenje standarda života i druge.

Kako bi se ublažio zagrijavajući utjecaj gradskih površina, danas se najčešće kao mjera urbanističkog uređenja koristi uvođenje zelene infrastrukture u gradove putem sadnje stabala i ozelenjivanjem površina te uređenjem zelenih krovova i zidova (Bowler i dr., 2010). Naime, podloge s prirodnim pokrovom imaju ohlađujući učinak u odnosu na umjetne podloge u izgrađenim dijelovima grada. Prirodna podloga na kojoj se nalazi trava, grmlje, drveće ili druga vegetacija ap-

‹ [01] Zelene površine u gradovima imaju ohlađujući učinak na zrak iznad njih, a u nekim slučajevima veliki parkovi sa šumskom vegetacijom mogu u prosjeku biti i do 2 °C hladniji u odnosu na izgrađenu okolicu – prizor iz Perivoja Zrinski u Čakovcu (Foto: Davorin Mance)

Green areas in cities have a cooling effect on the air above them, and in some cases large parks with forest vegetation can be on average up to 2 °C colder than the built environment – a scene from the Zrinski Park in Čakovec (Photo: Davorin Mance)



[02] Vertikalni profil temperature zraka u gradu i ruralnoj okolici (Nacrtala: Mirjana Mandić)
Vertical profile of air temperature in the city and rural surroundings (Drawn by: Mirjana Mandić)

sorbira manju količinu Sunčeve radijacije od podloge koja je izgrađena od umjetnih materijala te je danju hladnija, a preko noći se brže ohladi (Spronken-Smith i Oke, 1998; Oliveira i dr., 2011; Doick i Hutchings, 2013). Podloga na kojoj prevladava drveće, odnosno šuma prima još manje radijacije jer se znatan dio Sunčeve radijacije reflektira od gornjeg sloja krošanja – oko 10 do 30% (Birkebak i Birkebak, 1964; Shahidan i dr., 2006) – te i ne dopire do šumskog tla. U prosjeku je albedo, koeficijent refleksije Sunčeve radijacije, veći na prirodnoj podlozi nego na umjetnoj. Osim toga, biljni pokrivač dio radijacije troši i na proces fotosinteze. Dio se topline na prirodnim podlogama troši i na proces evapotranspiracije – isparavanja vode s podloge i iz biljaka, pri čemu se zbog velikog toplinskog kapaciteta vode veže znatna količina topline koja je sadržana u česticama vodene pare i ne sudjeluje u zagrijavanju zraka. Zbog svih tih procesa zelene površine imaju ohlađujući učinak na zrak iznad njih te se govori o hladnim otocima zelenih površina (eng. Green Space Cool Island – GSCI), odnosno hladnim otocima parkova (eng. Park Cool Island – PCI) (sl. 02), čiji ohlađujući učinak još više dolazi do izražaja (Erell i dr., 2011).

Mikroklimatska obilježja parkova

Ohlađujući učinak parkova ovisi o mnogo čimbenika – njihovoj veličini, vrsti tla i vegetacije, udjelu vodenih i izgrađenih površina, sinoptičkoj situaciji, dobu dana ili godine i drugim. Najvažniji čimbenik koji utječe na intenzitet PCI-a je veličina parka. Istraživanja su pokazala da se ohlađujući učinak zelenih površina može primijetiti već i na zelenim površinama veličine oko 200 metara (Erell i dr., 2011), iako tako male zelene površine nemaju ohlađujući utjecaj na izgrađeno područje u okolici. PCI je izraženiji što je veća površina parkova (Oke i dr., 1989; Chang i dr., 2007; Brandt i dr., 2016), a u nekim slučajevima veliki parkovi sa šumskom vegetacijom, površinom veći od 10 ha, mogu biti u prosjeku i do 2 °C hladniji u odnosu na izgrađenu okolicu (Anjos i Lopes, 2017; Aram i dr., 2019).

Toplinska obilježja parkova uvelike ovise o vrsti vegetacije koja u njemu prevladava te svaki park ne mora u svako doba dana ili godine biti nužno hladniji od izgrađene okolice, što se često ne uzima u obzir pri urbanom planiranju i uređenju parkova (Erell i dr., 2011). U parkovima u kojima veći dio površine pokriva drveće (šuma) do izražaja dolazi ohlađivanje tijekom dana. Krošnje stabala tijekom dana stvaraju sjenu, čime pomažu u smanjenju zagrijavanja podloge i zraka iznad nje (Norton i dr., 2014). Ako je riječ o gušćoj šumi, njezin je ohlađujući učinak veći pa maksimum PCI-a dolazi do izražaja poslijepodne, a ako je šumski pokrov nešto rjeđi, maksimum PCI-a nastupa rano navečer. Tijekom noći PCI ne dolazi toliko do izražaja jer krošnje stabala sprečavaju ohlađivanje dugovalnom radijacijom, a tome pridonosi i veća relativna vlažnost zraka koja je svojstvena šumskim prostorima zbog veće evapotranspiracije i slabije cirkulacije zraka (Souch i Souch, 1993; Brooks i Kyker-Snowman, 2008). U umjerenim geografskim širinama, gdje zime mogu biti vrlo hladne, povoljna je okolnost ako prevladavaju listopadne vrste drveća koje zimi gube lišće, čime omogućuju veće zagrijavanje podloge. Naime, krošnje listopadnog drveća s lišćem mogu smanjiti dolaznu Sunčevu radijaciju za 80 do 85 posto, a krošnje bez lišća samo za 30 do 45 posto (Andrade i Vieira, 2007).

U parkovima u kojima prevladavaju otvoreni travnjaci s malo ili nimalo rijetkih stabala PCI je najizraženiji tijekom noći (Erell i dr., 2011). Tijekom dana ne postoje krošnje koje bi sprečavale intenzivno zagrijavanje podloge, a evapotranspiracija ima veći ohlađujući učinak jedino ako se zelene površine navodnjavaju ili prskaju vodom. Razlike u temperaturi tih parkova i izgrađene okolice danju postoje, ali nisu toliko velike kao noću. Tada do izražaja dolazi jako ohlađivanje dugovalnom radijacijom pa je PCI znatno jači nego danju. Zbog nižih temperatura tijekom noći evaporacija je slaba i nema veći učinak na ohlađivanje. Za tu je vrstu parkova karakteristično da dnevne temperature zraka ponekad mogu biti i više nego na izgrađenim površinama oko parka.

Parkovi utječu i na cirkulaciju zraka u gradovima. Razlika u temperaturi zraka između parkova i izgrađene okolice potiče strujanje zraka u neposrednoj okolici parka zbog čega dolazi do širenja ohlađujućeg utjecaja PCI-a na neposredni prostor uz njega. Na intenzitet ohlađivanja utječu i brzina i smjer vjetra. Kada je atmosfera mirna, miješanje zraka je slabo te je razlika u temperaturi parka i okolice velika. S povećanjem brzine vjetra povećava se i miješanje zraka te, osobito u slučaju malih parkova, njihov ohlađujući učinak slabi. Ohlađujući se učinak PCI-a osjeća u smjeru puhanja vjetra, ali s udaljenošću vrlo brzo opada. Na to velik utjecaj ima veličina i gustoća zgrada u okolici parkova. Zbog toga se i horizontalni gradijent temperature zraka u okolici parkova dosta mijenja, što objašnjava često kontradiktorne rezultate različitih istraživanja prema kojima je ohlađujući utjecaj parkova u nekim slučajevima zanemariv, dok se u drugim slučajevima on može detektirati na udaljenostima od čak nekoliko stotina metara (Erell i dr., 2011).

Unatoč tome što ohlađujući učinak parkova raste s njihovom veličinom, povoljniji učinak na ublažavanje toplinskog otoka grada ima veći broj manjih parkova nego nekoliko velikih (Oke i dr., 2017). Kako se ohlađujući utjecaj parkova osjeća na izgrađenom području grada oko njih, utjecaj većeg broja relativno manjih parkova osjećat će se u dijelovima gdje se oni nalaze te će imati veći ukupni utjecaj na toplinska obilježja grada. Nasuprot tome, nekoliko velikih parkova koji imaju veći ohlađujući učinak u neposrednoj okolici neće se osjetiti u udaljenijim dijelovima grada. Posebno to vrijedi za velike, izolirane pakove na rubu gradova.

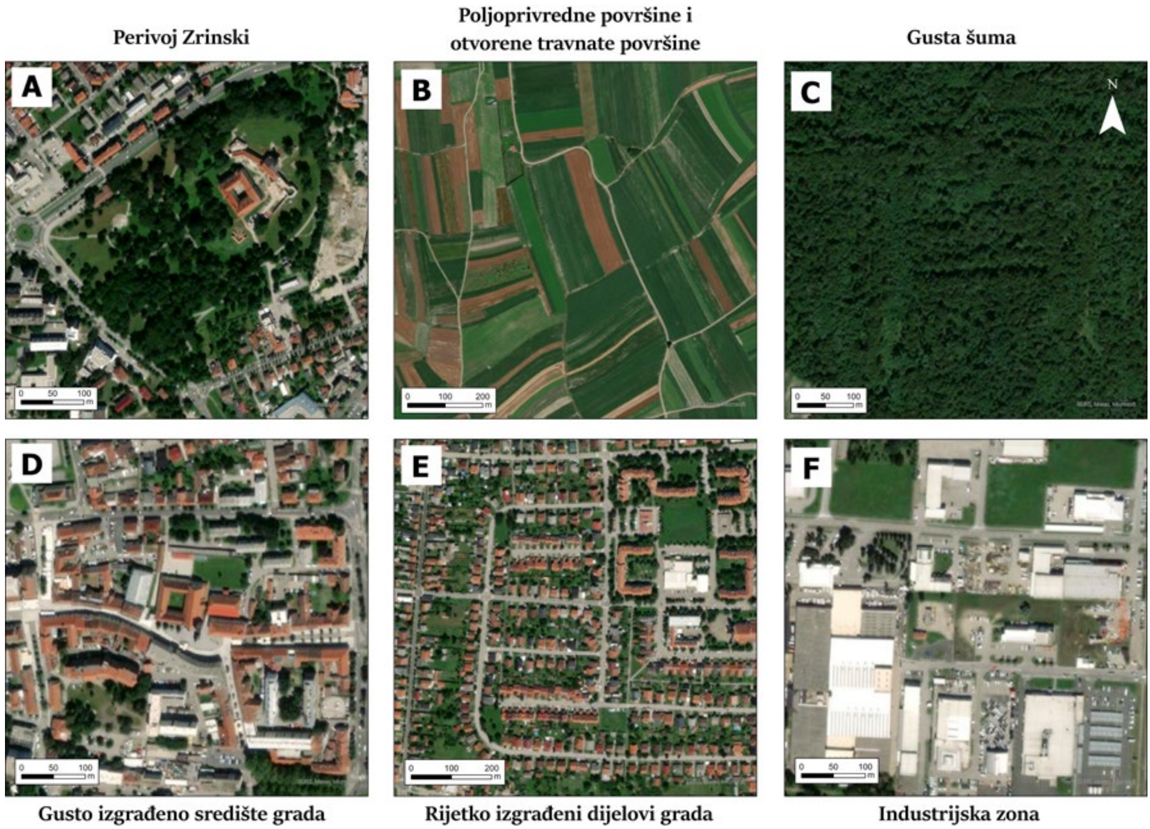
Perivoj Zrinski u Čakovcu kao primjer hladnog otoka

Analiza ohlađujućeg utjecaja parkova u ovom je članku provedena na primjeru parka Perivoj Zrinski (spomenik parkovne arhitekture Perivoj Zrinski) u Čakovcu. Kako je analiza toplinskih obilježja grada često ograničena malim brojem meteoroloških postaja, ova je analiza provedena korištenjem podataka Landsat-8 satelita o temperaturnim obilježjima Čakovca i okolice. Potrebno je naglasiti da sateliti mjere površinsku temperaturu (eng. land surface temperature – LST), tj. temperaturu podloge, dok meteorološke postaje mjere temperaturu zraka na dva metra visine.

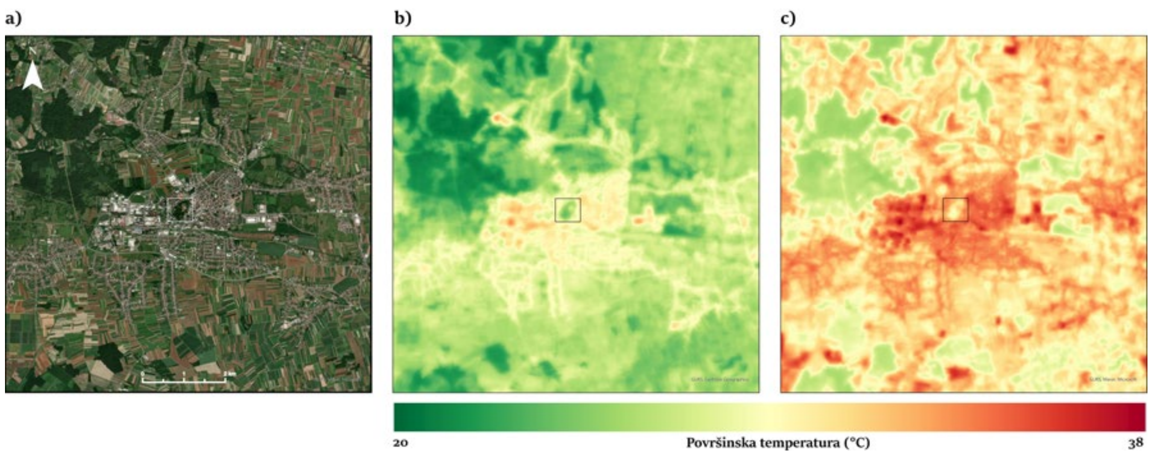
Za lakšu usporedbu toplinskih obilježja Perivoja Zrinski sa širim područjem grada Čakovca analiza je dopunjena izdvajanjem lokalnih klimatskih zona (eng. local climate zones – LCZ). Naime, gradovi nisu homogeni, nego se mogu izdvojiti područja koja imaju slična mikroklimatska obilježja na temelju obilježja podloge, vrste materijala, ljudske aktivnosti i dr. (Stewart i Oke, 2012). Iako navedena klasifikacija raspoznaje 17 različitih klasa LCZ-ja, za potrebe ovog rada izdvojeno je pet specifičnih klasa na području grada Čakovca i neposredne okolice te Perivoj Zrinski kao gradski park (sl. 03). Na temelju prikupljenih satelitskih mjerenja izračunate su prosječne vrijednosti LST-a u navedenim klasama za ljeto (mjeseci lipanj, srpanj i kolovoz) od 2013. do 2021. godine te su određene vrijednosti LST-a za 24. lipnja 2021. godine. Taj je dan odabran jer je bio u vrijeme trajanja jednog od najizraženijih toplinskih valova 2021. godine (DHMZ, 2021).

Gustoća izgrađenosti, udio nepropusnih površina te udio i vrsta zelenih površina imaju direktan utjecaj na LST (Oke i dr., 2017). Prema navedenim morfološkim obilježjima na području grada Čakovca izdvojene su sljedeće klase LCZ-ja: *Perivoj Zrinski, Poljoprivredne površine i otvorene travnate površine, Guste šume, Gusto izgrađeno središte grada, Rijetko izgrađeni dijelovi grada* i *Industrijska zona* (sl. 03).

S obzirom na ohlađujući utjecaj zelenih površina, može se pretpostaviti da će područja s većim udjelom zelenila pokazivati niže vrijednosti LST-ja, što snimke Landsat-8 satelita i potvrđuju (sl. 04). Najniže srednje ljetne vrijednosti LST-ja od 2013. do 2021. godine iznose do 20 °C , a javljaju se u šumovitim područjima smještenim sjeverozapadno od Čakovca (sl. 03c i 04b). Izdvaja se i središnja

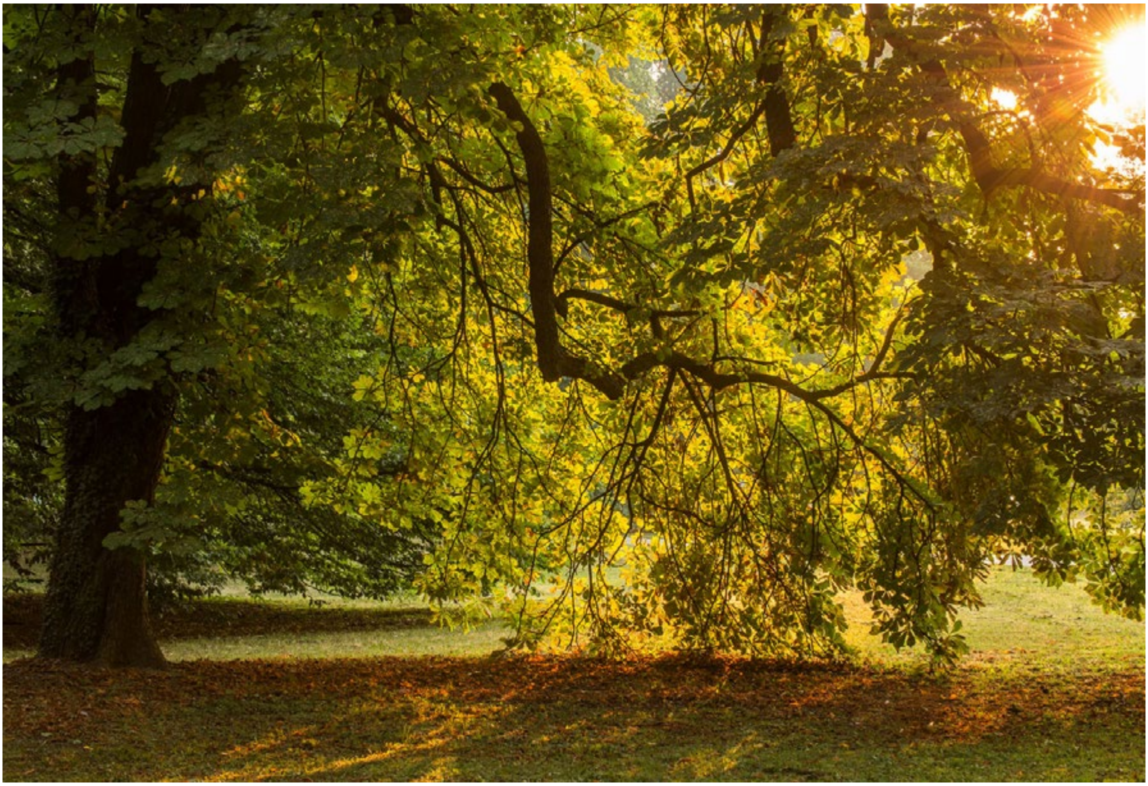


[03] Morfološka obilježja odabranih lokalnih klimatskih zona u gradu Čakovcu (Priredio: Matej Žgela)
Morphological characteristics of selected local climatic zones in the town of Čakovec
(Prepared by: Matej Žgela)



[04] Satelitski prikaz grada Čakovca (a); srednja ljetna površinska temperatura za razdoblje od 2013. do 2021. (b); površinska temperatura 24. lipnja 2021. (c).
Četverokut na slici označava područje gdje se nalazi Perivoj Zrinski (Priredio: Matej Žgela)
Satellite view of the town of Čakovec (a); mean summer surface temperature for the period 2013 to 2021 (b); surface temperature 24 June 2021 (c).
The square in the picture indicates the area where Zrinski Park is located (Prepared by: Matej Žgela)

[05] Perivoj Zrinski izdvaja se kao hladni otok u gradu Čakovcu tijekom ljeta – prizori iz perivoja (Foto: Davorin Mance)
Zrinski Park stands out as a cold island in the town of Čakovec during the summer - scenes from the park (Photo: D. Mance)



zona povišenih vrijednosti LST-ja vezana za sam grad Čakovec (sl. 03d, 03e i 04b), tj. formiran je površinski UHI. Ondje je LST ponegdje i za 10 – 15 °C viši u odnosu na spomenuta šumovita područja. *Perivoj Zrinski* okružen je izgrađenim područjem s visokim vrijednostima LST-ja, no on je sam hladni otok sa znatno nižim LST-jem (sl. 03a i 04b). Uz središnji UHI grada, tu su i mikro toplinski otoci koji su se formirali na izdvojenim industrijskim zonama izvan grada. Za njih je također karakterističan izostanak vegetacije te visoki LST (sl. 03f).

Tijekom toplinskog vala u Hrvatskoj 24. lipnja 2021. godine na cijelom istraživanom području grada Čakovca vrijednosti LST-ja su vrlo visoke, s maksimumom od gotovo 40 °C (sl. 04c). Međutim, kako Landsat-8 prolazi iznad Čakovca oko 10.45 sati, prikazane vrijednosti LST-ja ne predstavljaju najviše temperature u danu koje se javljaju oko 13 sati. U vrijeme toplinskog vala LST je na cijelom području veći za otprilike 5 °C u odnosu na srednje ljetne vrijednosti LST-ja od 2013. do 2021. godine. Riječ je o znatnoj temperaturnoj razlici koja ukazuje na intenzitet UHI-a te na njegove negativne posljedice, od kojih je potrebno izdvojiti štetan učinak na zdravstveno stanje stanovništva. Na sl. 04c se također ističu izrazito zagrijane poljoprivredne površine (sl. 03b). Naime, poljoprivredne površine tijekom godine mijenjaju pokrivenost vegetacijom. Primjerice, ljeti kao posljedica žetve velik udio obradivih površina gubi vegetacijski pokrivač te ostaje golo tlo, zbog čega dolazi do velikih promjena u albedu, a time i povećane apsorpcije dolazne Sunčeve radijacije i viših vrijednosti površinske temperature.

Iako se na sl. 04 dobro uočava ovisnost LST-ja o toplinskim obilježjima podloge, to još bolje potvrđuju podaci o srednjim vrijednostima LST-ja za odabrane LCZ u ljetnom razdoblju od 2013. do 2021. godine i u vrijeme toplinskog vala (donja tablica). Temperaturne razlike između *Perivoja Zrinski* i drugih LCZ-ja pokazuju vrlo slične vrijednosti. *Perivoj Zrinski* ima druge po redu najniže vrijednosti LST-ja, odmah nakon *Guste šume* koja je hladnija za 2,2 °C od 2013. do 2021. te 2,5 °C u vrijeme toplinskog vala. *Gusto izgrađeno središte grada* je u oba slučaja za

Lokalna klimatska zona	LST 2013-2021	diff LCZ_PZ – LCZx	LST 24/06/2021	diff LCZ_PZ – LCZx
Perivoj Zrinski	**24,7**	-	**29,5**	-
Gusta šuma	22,5	-2,2	27,0	-2,5
Poljoprivredne površine i otvorene travnate površine	26,3	+1,6	30,9	+1,4
Rijetko izgrađeni dijelovi grada	28,3	+3,6	32,7	+3,2
Industrijska zona	29,6	+4,9	34,3	+4,8
Gusto izgrađeno središte grada	30,6	+5,9	35,1	+5,6

Vrijednosti površinske temperature (°C) za odabrane lokalne klimatske zone (LCZx) grada Čakovca s temperaturnim razlikama u odnosu na Perivoj Zrinski (LCZ_PZ) za ljeto u razdoblju od 2013. do 2021. godine te za 24. lipnja 2021.

gotovo 6 °C toplije u odnosu na gradski park, pri čemu je zanimljivo napomenuti kako je njihova udaljenost samo oko 500 metara zračne linije. Iz ovog je primjera vidljivo kako su u gradu moguće velike promjene vrijednosti LST-a, što je posljedica heterogenosti gradova, odnosno promjene obilježja podloge na malim udaljenostima, u ovom slučaju između gradskog parka *Perivoj Zrinski* i *Gusto izgrađenog središta grada*. U klasi *Rijetko izgrađeni dijelovi grada* također je primjetan utjecaj vegetacije na smanjenje LST-ja te je ova klasa za čak 2,3 °C hladnija od *Gusto izgrađenog središta grada*, ali i za 3,6 °C toplija od *Perivoja Zrinski* u razdoblju od 2013. do 2021. te 2,4 °C u vrijeme toplinskog vala.

Iako se u ovom radu ne analiziraju temperature zraka, postoji važna korelacija LST-ja i temperature zraka (Good, 2016; Good i dr., 2017; Gallo i dr., 2011) pa se može tvrditi kako niže vrijednosti LST-ja znače i niže vrijednosti temperature zraka.

Zelene površine u gradovima imaju važnu ulogu u smanjenju nepovoljnog utjecaja toplinskog otoka grada, a uz to parkovi pružaju i rekreacijske usluge njegovim stanovnicima. Implementacija drvoreda u prometnim ulicama može utjecati na smanjenje buke i onečišćenja zraka, a istodobno pruža potreban hlad kako se podloga ne bi previše zagrijala. *Perivoj Zrinski* dobar je primjer parka koji smanjuje učinak UHI-a, umanjuje toplinski stres kod stanovništva i povećava kvalitetu života.

LITERATURA

Andrade, H., Vieira, R., 2007: A climatic study of an urban green space: the Gulbenkian park in Lisbon (Portugal), *Finisterra* XLII (84), 27-46.

Anjos, M., Lopes, A., 2017: Urban Heat Island and Park Cool Island Intensities in the Coastal City of Aracaju, North-Eastern Brazil, *Sustainability* 9 (8), 1-17.

Aram, F., Higueras García, E., Solgi, E., Mansournia, S., 2019: Urban green space cooling effect in cities, *Heliyon* 5 (4), e01339.

Birkebak, R., Birkebak, R., 1964: Solar Radiation Characteristics of Tree Leaves, *Ecology* 45 (3), 646-649.

Brandt, L., Derby Lewis, A., Fahey, R., Scott, L., Darling, L., Swanston, C., 2016: A framework for adapting urban forests to climate change, *Environmental Science & Policy* 66, 393-402.

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.

Brooks, R. T., Kyker-Snowman T. D., 2008: Forest floor temperature and relative humidity following timber harvesting in southern New England, USA, *Forest Ecology and Management* 254 (1), 65-73.

Chang, C. R., Li, M. H., Chang, S. D., 2007: A preliminary study on the local cool-island intensity of Taipei city parks, *Landscape and Urban Planning* 80 (4), 386-395.

DHMZ, 2021: *Meteorološki i hidrološki bilten, lipanj*, Državni hidrometeorološki zavod, Zagreb, https://meteo.hr/proizvodi.php?section=publikacije&param=publikacije_publikacije_dhmz&el=bilteni

Doick, K., Hutchings, T., 2013: *Air temperature regulation by urban trees and green infrastructure*, Forestry Commission.

Erell, E., Pearlmutter, D., Williamson, T., 2011: *Urban Microclimate - Designing the Spaces Between Buildings*, Routledge, New York, 288.

Gallo, K., Hale, R., Tarpley, D., Yu, Y., 2011: Evaluation of the Relationship between Air and Land Surface Temperature under Clear- and Cloudy-Sky Conditions, *Journal of Applied Meteorology and Climatology* 50 (3), 767-775.

Good, E. J., 2016: An in situ-based analysis of the relationship between land surface »skin« and screen-level air temperatures, *Journal of Geophysical Research: Atmospheres* 121, 8801–8819.

Good, E. J., Ghent, D. J., Bulgin, C. E., Remedios, J. J., 2017: A spatiotemporal analysis of the relationship between near-surface air temperature and satellite land surface temperatures using 17 years of data from the ATSR series, *Journal of Geophysical Research: Atmospheres* 122, 9185– 9210.

Norton, B. N., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., Williams, N. S. G., 2014: Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes, *Landscape and Urban Planning* 134 (1), 127-138.

Oke, T. R., Crowther, J. M., McNaughton, K. G., Monteith, J. L., Gardiner, B., 1989: The Micrometeorology of the Urban Forest [and Discussion], Philosophical Transactions of the Royal Society of London, Series B, *Biological Sciences* 324 (1223), 335-349.

Oke, T. R., Mills, G., Christen, A., Voogt, J. A., 2017: *Urban Climates*, Cambridge University Press, Cambridge, 548 str.

Oliveira, S., Andrade, H., Vaz, T., 2011: The cooling effect of green spaces as a contribution to the mitigation of urban heat: a case study in Lisbon, *Building and Environment* 46 (11), 2186-2194.

Shahidan, M. F., Salleh, D. E., Shariff, M. K. M., 2006: The Influence of Tree Canopy on the Thermal Environment in a Tropical Climate: A Preliminary Study, *Proceedings of the 2nd iNTA Conference 2006: Harmony in Culture and Nature*, Jogjakarta, Indonezija.

Souch, C. A., Souch, C., 1993: The effect of trees on summertime below canopy urban climates: a case study Bloomington, Indiana, *Journal of Arboriculture* 19 (5), 303-312.

Spronken-Smith, R. A., Oke, T. R., 1998: The thermal regime of urban parks in two cities with different summer climates, *International Journal of Remote Sensing* 19 (11), 2085-2104.

Stewart, I. D., and Oke, T. R., 2012: Local climate zones for urban temperature studies, *Bulletin of the American Meteorological Society* 93 (1), 1879–1900.

SAŽETAK

Klimatsko značenje parkova u urbanim područjima

Zelene površine imaju ohlađujući učinak na zrak iznad njih, a ta se pojava naziva hladni otok zelenih površina (eng. Green Space Cool Island – GSCI), odnosno hladni otok parkova (eng. Park Cool Island – PCI) koji se javlja na prostoru toplinskog otoka grada (eng. Urban Heat Island – UHI). Osnovni je uzrok te pojave činjenica da prirodna podloga apsorbira manju količinu Sunčeve radijacije od podloge koja je izgrađena od umjetnih materijala te je danju hladnija, a noću se brže ohladi dugovalnom radijacijom. Ohlađujući učinak još više dolazi do izražaja ako na podlozi prevladava drveće, odnosno šuma. Intenzitet ohlađivanja parkova u odnosu na izgrađenu okolicu ovisi o mnogo čimbenika – njihovoj veličini, vrsti tla i vegetacije, udjelu vodenih i izgrađenih površina, brzini i smjeru vjetra, dobu dana ili godine... Na mikroklimatska obilježja parkova velik utjecaj ima vrsta vegetacije koja u parku prevladava.

U parkovima u kojima veći dio površine pokriva drveće, odnosno šuma do izražaja dolazi ohlađivanje tijekom dana, a u parkovima u kojima prevladavaju otvoreni travnjaci s malo ili nimalo rijetkih stabala ohlađivanje je najizraženije tijekom noći. Parkovi s travnjacima mogu u specifičnim uvjetima tijekom dana imati i više temperature zraka nego izgrađene površine u okolici.

Za urbano planiranje važna je zakonitost da ohlađujući učinak parkova raste s njihovom veličinom, kao i da povoljniji učinak na ublažavanje toplinskog otoka grada ima veći broj manjih parkova nego nekoliko velikih.

U članku je ohlađujući utjecaj parkova prikazan na primjeru spomenika parkovne arhitekture Perivoj Zrinski u Čakovcu, pri čemu su korišteni podaci Landsat-8 satelita o površinskoj temperaturi (engl. Land Surface Temperature – LST). Analiza je dopunjena izdvajanjem lokalnih klimatskih zona (eng. Local Climate Zones – LCZ) radi lakše usporedbe toplinskih obilježja pojedinih dijelova grada Čakovca i njegove ruralne okolice. Pokazalo se da se Perivoj Zrinski izdvaja kao hladni otok u gradu Čakovcu tijekom ljeta u istraživanom razdoblju od 2013. do 2021. te 24. lipnja 2021. godine u vrijeme toplinskog vala, čime pridonosi smanjenju nepovoljnog utjecaja toplinskog otoka grada i ima povoljan utjecaj na njegova klimatska obilježja, a time i na kvalitetu života stanovništva u gradu.

ÖSSZEFOGLALÓ

A városi területeken található parkok éghajlati jelentősége
A zöldterütek hűsítő hatással vannak a felettük lévő levegőre és ezt a jelenséget a zöldterületek hideg szigetének (Green Space Cool Island – GSCI) illetve a parkok hideg szigetének (Park Cool Island – PCI) nevezik, amely városi hőszigeteken jelentkezik. (ang. Urban Heat Island – UHI). Ennek a jelenségnek a kiváltó oka az a tény, hogy a természetes hordozó kevesebb napsugárzást szív fel mint a mesterséges anyagokból készült hordozó és nappal hidegebb, éjszaka pedig gyorsabban hűl le a hosszúhullámú sugárzással. A hűtőhatás még kifejezettebb, ha az aljzatot fák vagy erdők uralják. A parkok hűtésének intenzitása az épített környezethez viszonyítva számos tényezőtől függ - méretüktől, talaj- és növényzet típusától, a víz és a beépített területek arányától, a szél sebességétől és irányától, a napszaktól illetve az évszaktól... A parkok mikroklimatikus jellemzőit a parkban uralkodó növényzettípusok nagymértékben befolyásolják.

A parkokban, ahol a terület nagyobb részét fák vagy erdők borítják, napközben a legkifejezettebb a hűlés, a parkokban ahol pedig a nyílt pázsit dominál és kevés vagy ritka a fa, a lehűlés éjszaka a legkifejezettebb. A pázsittal ellátott parkokban, bizonyos körülmények között, a nap folyamán magasabb lehet a levegőhőmérséklet mint a beépített területek környékén.

A várostervezés szempontjából törvényszerűen fontos, hogy a parkok hűsítő hatása növekedjen méretüktől függően, valamint figyelembe kell venni azt is, hogy több kisebb méretű park kialakítása kedvezőbb hatást gyakorol a város hőszigetének hűtésére mint kevesebb nagyterületű park tervezése. A parkok hűsítő hatását mutatja be a cikk a csáktornyai Perivoj Zrinski (Zrínyi kastélypark) parképítészeti emlékmű példáján, melyben felhasználták a Landsat-8 műhold által bejegyzett földfelszíni hőmérsékletre (angol Land Surface Temperature – LST) vonatkozó adatokat. Az elemzést kiegészítették a helyi éghajlati zónák (angol Local Climate Zones – LCZ) felosztásával, hogy megkönnyítsék Csáktornya egyes városrészeinek és a város vidéki környezetében megfigyelt termikus jellemzőinek összehasonlítását. Kiderült, hogy a Perivoj Zrinski (Zrínyi kastélypark) hidegszigetként működik Csáktornya városában nyaranta a 2013-tól 2021-ig terjedő vizsgált időszak folyamán, valamint 2021. június 24-én a hőséghullám idején is és ezzel hozzájárul a hősziget káros hatásainak csökkentéséhez. és kedvezően hat a város éghajlati adottságaira, ezáltal a városban élő lakosság életminőségére is.

Climatic significance of parks in urban areas

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Thermal island of the city and parks

Cities modify the local climate of the area where they are located, which is most pronounced through a phenomenon called urban heat island (UHI). UHI is reflected in the higher air temperature in the city compared to its rural surroundings (Oke et al., 2017). The main cause of this phenomenon are artificial materials (asphalt, concrete and others) from which cities are built, and they absorb more solar short-wave radiation during the day than the natural background in the rural surroundings of the city. This accumulated heat warms up the city, which is most pronounced during the night and in winter, when cooling by long-wave radiation is strongest. The intensity of the heat island of the city depends on the size of the city, the density of buildings, its location, synoptic situation, time of day and year and other factors. The thermal island of the city has a direct impact on the lives of people in cities and affects the quality of life of their inhabitants, which is most evident through negative consequences - high day and night temperatures, air pollution, increased energy consumption, endangering human health, lower living standards and others.

In order to soften the warming impact of urban areas, the introduction of green infrastructure in cities through planting trees and landscaping and arranging green roofs and walls is most often used nowadays as a measure of urban planning (Bowler et al., 2010). Namely, substrates with natural cover have a cooling effect when compared to artificial substrates in built-up areas of the city. Natural substrates containing grass, shrubs, trees or other vegetation absorb less solar radiation than substrates made of artificial materials, which are colder during the day and cool faster during the night (Spronken-Smith and Oke, 1998; Oliveira et al., 2011; Doick and Hutchings, 2013). The substrate on which trees predominate, i.e. the forest receives even less radiation because a significant part of the Sun's radiation is reflected from the upper layer of the tree canopy - about 10 to 30% (Birkebak and Birkebak, 1964; Shahidan et al., 2006) - and does not reach the forest soil. On average, albedo, the reflection coefficient of solar radiation, is higher on natural substrates than on artificial ones. In addition, the plant cover spends part of the radiation on the process of photosynthesis as well. Part of the heat on natural substrates is spent on the process of evapotranspiration - evaporation of water from the substrate and from plants, where due to the high heat capacity of water, a significant amount of heat contained in water vapor particles binds and does not participate in air heating. Due to all these processes, green areas have a cooling effect on the air above them and we are talking about cold islands of green areas (Green Space Cool Island - GSCI), or cold islands of parks (Park Cool Island - PCI) (Fig. 02)., whose cooling effect is even more pronounced (Erell et al., 2011).

Microclimatic characteristics of parks

The cooling effect of parks depends on many factors - their size, type of soil and vegetation, the share of water and built-up areas, the synoptic situation, the time of day or year and others. The most important factor affecting PCI intensity is the size of the park. Research has shown that the cooling effect of green areas can be observed even on green areas of around 200 meters in size (Erell et al., 2011), although such small green areas do not have a cooling effect on the built-up area. The larger area of parks, the more pronounced PCI (Oke et al., 1989; Chang et al., 2007; Brandt et al., 2016), and in some cases large parks with forest vegetation, with an area of more than 10 ha, may be on average and up to 2 °C colder than the built environment (Anjos and Lopes, 2017; Aram et al., 2019).

The thermal characteristics of parks largely depend on the type of vegetation that prevails in it, and each park does not have to be colder than the built environment at any time of the day or year, which is often not taken into account in urban planning and landscaping (Erell et al., 2011). In parks where most of the area is covered with trees (forests), cooling during the day is most noticeable. Tree canopies create shade during the day, helping to reduce the warming of the substrate and the air above it (Norton et al., 2014). If it is a dense forest, its cooling effect is greater, so the maximum PCI occurs in the afternoon, and if the forest cover is slightly thinner, the maximum PCI occurs early in the evening. During the night, PCI is less pronounced because tree canopies prevent cooling by long-wave radiation, which occurs because of the higher relative humidity of forest areas due to greater evapotranspiration and poor air circulation (Souch and Souch, 1993; Brooks and Kyker-Snowman, 2008).). In temperate latitudes, where winters can be very cold, a favorable circumstance is if deciduous tree species that lose leaves in winter predominate, and by doing so they allow greater substrate warming. Namely, the canopy of deciduous trees with leaves can reduce incoming solar radiation by 80 to 85 percent, and the canopy without leaves by only 30 to 45 percent (Andrade and Vieira, 2007).

In parks where open grasslands with few or no sparse trees predominate, PCI is most pronounced during the night (Erell et al., 2011). During the day there are no canopies that would prevent intensive heating of the substrate, and evapotranspiration has a greater cooling effect only if the green areas are irrigated or sprinkled with water. The differences in the temperature of these parks and the built environment exist during the day, but they are not as great as at night. Then a strong cooling by long-wave radiation comes to the fore, so PCI is much stronger than during the day. Due to lower temperatures during the night, evaporation is weak and has no major effect on cooling. It is characteristic of this type of park that the daily air temperatures can sometimes be higher than in the built-up areas around the park.

Parks also affect air circulation in cities. The difference in air temperature between the parks and the built environment encourages the flow of air in the immediate vicinity of the park, which leads to the spread of the cooling effect of PCI on the immediate area next to it. The intensity of cooling is also influenced by the speed and direction of the wind. When the atmosphere is calm, the mixing of the air is weak so the difference in temperature between the park and the surroundings is large. As the wind speed increases, so does the mixing of the air and, especially in the case of small parks, their cooling effect weakens. The cooling effect of PCI is felt in the direction of the wind blowing, but decreases very quickly with distance. This is greatly influenced by the size and density of the buildings around the parks. Therefore, the horizontal air temperature gradient around the parks changes a lot, which explains the often contradictory results of various studies according to which the cooling effect of parks is in some cases negligible, while in other cases it can be detected at distances of several hundred meters (Erell and dr., 2011).

Despite the fact that the cooling effect of parks increases with park size, a larger number of smaller parks have a more favorable effect on mitigating the city's heat island than several large ones (Oke et al., 2017). As the cooling impact of parks is felt in the built-up area of the city around them, the impact of a number of relatively smaller parks will be felt in the parts where they are located and will have a greater overall impact on the city's thermal features. On the contrary, several large parks that have a greater cooling effect in the immediate vicinity will not be felt in more remote parts of the city. This is especially true for large, isolated parks on the edge of cities.

Zrinski Park in Čakovec as an example of a cold island

The analysis of the cooling effect of parks in this article was carried out on the example of Zrinski Park (horticultural monument) in Čakovec. As the analysis of the thermal characteristics of the town/city is often limited to a small number of meteorological stations, this analysis was conducted using Landsat-8 satellite data on the temperature characteristics of Čakovec and its surroundings. It should be emphasized that satellites measure land surface temperature (LST), i.e. the temperature of the substrate, while meteorological stations measure air temperature at two meters altitude.

For easier comparison of the thermal characteristics of Zrinski Park with the wider area of the town of Čakovec, the analysis was supplemented by the separation of local climate zones (LCZ). Namely, towns/cities are not homogeneous, but areas that have similar microclimatic characteristics can be singled out based on the characteristics of the substrate, types of materials, human activities, etc. (Stewart and Oke, 2012). Although the mentioned classification recognizes 17 different classes of LCZ, for the purposes of this paper, five specific classes in the area of town Čakovec with its immediate surroundings and Zrinski Park as a town park have been singled out (Fig. 03). Based on the collected satellite measurements, the average values of LST in these classes for the summer (June, July and August) from 2013 to 2021 were calculated, and the values of LST for June 24, 2021 were determined. That day was chosen because it was at the time of one of the most pronounced heat waves in 2021 (Croatian Meteorological and Hydrological Service DHMZ, 2021).

Building density, the share of impermeable areas and the share and type of green areas have a direct impact on LST (Oke et al., 2017). According to the mentioned morphological features in the town Čakovec area, the following classes of LCZ were singled out: *Zrinski Park, Agricultural areas and open grass areas, Dense forests, Densely built town center, Rarely built parts of the and Industrial zone* (Fig. 03).

Given the cooling effect of green areas, it can be assumed that areas with a higher share of greenery will show lower LST values, which is confirmed by Landsat-8 satellite images (Fig. 04). The lowest average summer values of LST from 2013 to 2021 are up to 20 °C , and they occur in forested areas located northwest of Čakovec (Figs. 03c and 04b). The central zone of elevated LST values related to the town of Čakovec itself also stands out (Figs. 03d, 03e and 04b), ie the surface UHI is formed. LST

Local climate zone	LST 2013-2021	diff LCZ_PZ – LCZx	LST 24/06/2021	diff LCZ_PZ – LCZx
Zrinski Park	**24,7**	-	**29,5**	-
Dense forest	22,5	-2,2	27,0	-2,5
Agricultural land and open grassland	26,3	+1,6	30,9	+1,4
Rarely built parts of the city	28,3	+3,6	32,7	+3,2
Industrial zone	29,6	+4,9	34,3	+4,8
Densely built town center	30,6	+5,9	35,1	+5,6

Values of surface temperature (°C) for selected local climate zones (LCZx) of the town of Čakovec with temperature differences in relation to Zrinski Park (LCZ_PZ) for the summer in the period from 2013 to 2021 and for June 24, 2021.

there is sometimes 10 - 15 °C higher than the mentioned forested areas. *Zrinski Park* is surrounded by a built-up area with high LST values, but the park itself is a cold island with significantly lower LST (Figs. 03a and 04b). In addition to the central UHI of the town, there are also micro thermal islands that have formed in separate industrial zones outside the town. They are also characterized by a lack of vegetation and high LST (Fig. 03f).

During the heat wave in Croatia on June 24, 2021, the LST values in the entire researched area of the town of Čakovec were very high, with a maximum of almost 40 °C (Fig. 04c). However, as Landsat-8 passes over Čakovec around 10.45 am, the LST values shown do not represent the highest temperatures of the day which occur around 1 pm. At the time of the heat wave, the LST in the whole area is higher by approximately 5 °C compared to the average summer values of the LST from 2013 to 2021. This is a significant temperature difference that indicates the intensity of UHI and its negative consequences, of which it is necessary to single out the harmful effect on the health of the population. Fig. 04c also highlights extremely heated agricultural areas (Fig. 03b). Namely, agricultural areas change their vegetation coverage during the year. For example, in summer, as a result of harvest, a large share of arable land loses vegetation and bare soil remains, resulting in large changes in albedo, and thus increased absorption of incoming solar radiation and higher surface temperature values.

Although the dependence of LST on the thermal characteristics of the substrate can be clearly seen in Fig. 04, this is even better confirmed by the data on the mean LST values for selected LCZs in the summer period from 2013 to 2021 and during the heat wave (Table above). Temperature differences between *Zrinski Park* and other LCZs show very similar values. *Zrinski Park* has the second lowest LST values, right after the *Dense Forest*, which is 2.2 °C colder from 2013 to 2021 and 2.5 °C during the heat wave. The *Densely built town center* is in both cases almost 6 °C warmer than the town park, and it is interesting to note that their distance is only about 500 meters as the crow flies. This example shows that large changes in LST values are possible in the town, which is due to the heterogeneity of towns/cities, i.e. changes in the characteristics of the substrate over short distances, in this case between the town park *Zrinski Park* and *The densely built town center*. In the class *Rarely built parts of the town*, the influence of vegetation on the reduction of LST is also noticeable, and this class is as much as 2.3 °C colder than the *Densely built town center*, but also 3.6 °C warmer than *Zrinski Park* in the period from 2013 by 2021 and 2.4 °C during the heat wave.

Although air temperatures are not analyzed in this paper, there is an important correlation between LST and air temperature (Good, 2016; Good et al., 2017; Gallo et al., 2011), so it can be argued that lower LST values also mean lower air temperature values.

Green areas in towns/cities play an important role in reducing the adverse effects of the city's heat island, and parks also provide recreational services to its residents. The implementation of tree lines in busy streets can reduce noise and air pollution, and at the same time provide the necessary shade so that the substrate does not overheat. *Zrinski Park* is a good example of a park that reduces the impact of UHI, reduces heat stress in the population and increases the quality of life.

SUMMARY

Climatic significance of parks in urban areas

Green areas have a cooling effect on the air above them, and this phenomenon is called the cold island of green areas (Green Space Cool Island - GSCI), or cold island of parks (Park Cool Island - PCI) that occurs in the area of the heat island (eng. Urban Heat Island - UHI). The main cause of this phenomenon is the fact that the natural substrate absorbs less solar radiation than the substrate made of artificial materials and is colder during the day and cools faster at night with long-wave radiation. The cooling effect is even more pronounced if the substrate is dominated by trees i.e. forests. The intensity of cooling of parks in relation to the built environment depends on many factors - their size, type of soil and vegetation, the share of water and built-up areas, wind speed and direction, time of day or year... Microclimatic characteristics of the parks are greatly influenced by the type of vegetation that predominates in the park.

In parks where most of the area is covered with trees i.e. forests, cooling is most pronounced during the day, and in parks where open lawns with few or no sparse trees predominate, cooling is most pronounced during the night. Parks with lawns can have higher air temperatures during the day in specific conditions than built-up areas around them. For urban planning it is very important that the cooling effect of parks increases with their size, as well as that a larger number of smaller parks than a few large ones have a more favorable effect on softening the city's heat island.

The cooling effect of parks in the article is presented on the example of the horticultural monument Zrinski Park in Čakovec, using data from Landsat-8 satellites on land surface temperature (LST). The analysis was supplemented by the selection of local climate zones (LCZ) in order to facilitate the comparison of thermal characteristics of certain parts of the town of Čakovec and its rural surroundings. It turned out that Zrinski Park stands out as a cold island in the town of Čakovec during the summer in the study period from 2013 to 2021 and June 24, 2021 during the heat wave, which reduces the adverse effects of heat on the island and has a positive impact on its climatic characteristics, and thus on the quality of life of the town population.