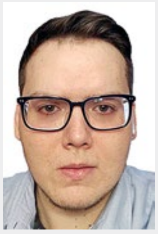
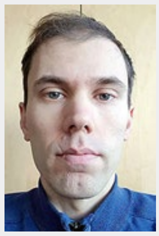
The effect of urban microenvironment on indoor temperatures in Helsinki region



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The influence of the urban microenvironment on indoor air temperature was studied. The large dataset of over 2000 apartments in the Helsinki region was analyzed during the heat waves of 2018 and 2021. Buildings were clustered into groups by geographical location, green view index, floor area ratio and distance from the sea. The results showed that the urban microenvironment had a maximum of up to 1°C effect on indoor air temperature. The green view index and distance from the sea had both the strongest temperature-reducing effect of about 0.5°C. The urban microenvironment factors had a lesser impact during long heatwaves and the most significant impact was during short heatwaves.

Keywords: urban microenvironment, residential buildings, overheating, heatwave, indoor air temperature

Extreme weather conditions in changing Nordic climate

Due to climate change extreme weather events are becoming more frequent and severe, resulting in local heatwaves and, subsequently, overheating of residential buildings [1,2]. Overheating of residential building stock can adversely affect the quality of rest and health, especially during severe heat waves [3,4].

Mechanical cooling is not commonly implemented in the Finland residential building stock, as the cooling period has been rather short, and the buildings are designed to have high insulation and airtightness due to cold weather conditions [5–9]. Because of this, in the summertime with extreme weather conditions, buildings are less capable of dissipating heat during the nighttime if the outdoor environment temperature stays quite high. For instance, the year 2050 heatwave scenario, will bring about 3000 degree hours above 32°C indoor temperature of building stock [10]. Hence, it becomes essential to make buildings more resilient for hot summers and to prevent overheating.

There are several main factors contributing to building stock overheating – weather and such complex phenomena as the urban heat island (UHI) effect. It shows a correlation with urbanization, high direct and indirect solar radiation (solar insolation reflection), low urban vegetation level and high floor area ratio [11,12]. The overheating risk, brought by UHI, could be prevented on the district level with wise urban microenvironment design: urban vegetation, open water sources and low-emission building envelope.

Analyzed heat waves and selected urban microenvironment factors

The study focuses on the effect of the urban microenvironment parameters in Nordic conditions during the summer and severe heat waves of 2018 and 2021. For the analysis different heat wave periods were chosen: early summer, and late summer. The green view index (GVI), floor area ratio (building's floor area in relation to the size of the lot/parcel that the building is located on) and building distance from see were chosen to represent microenvironment parameters. The large dataset allows analysis of urban microenvironment factors. The factors were distinguished from others by clustering close-situated building groups with the same factors, averaging the influence of others. The effect of urban microenvironment parameters on indoor air temperature was calculated for each period separately.

In Finland, the heatwaves were defined as hot days when a maximum hourly temperature exceeded 25°C. In this analysis, the periods were chosen accordingly (see **Fig.1**):

- The first period was in the early summer, characterized by typical warm early summer days.
- The second period was a short heat wave transitioning from a normal summer day to a hot day.
- The third period was a long heat wave in midsummer. The urban environment and seawater were already warmed up.
- The fourth period was in late summer. The urban and natural environment was still warm after summer.

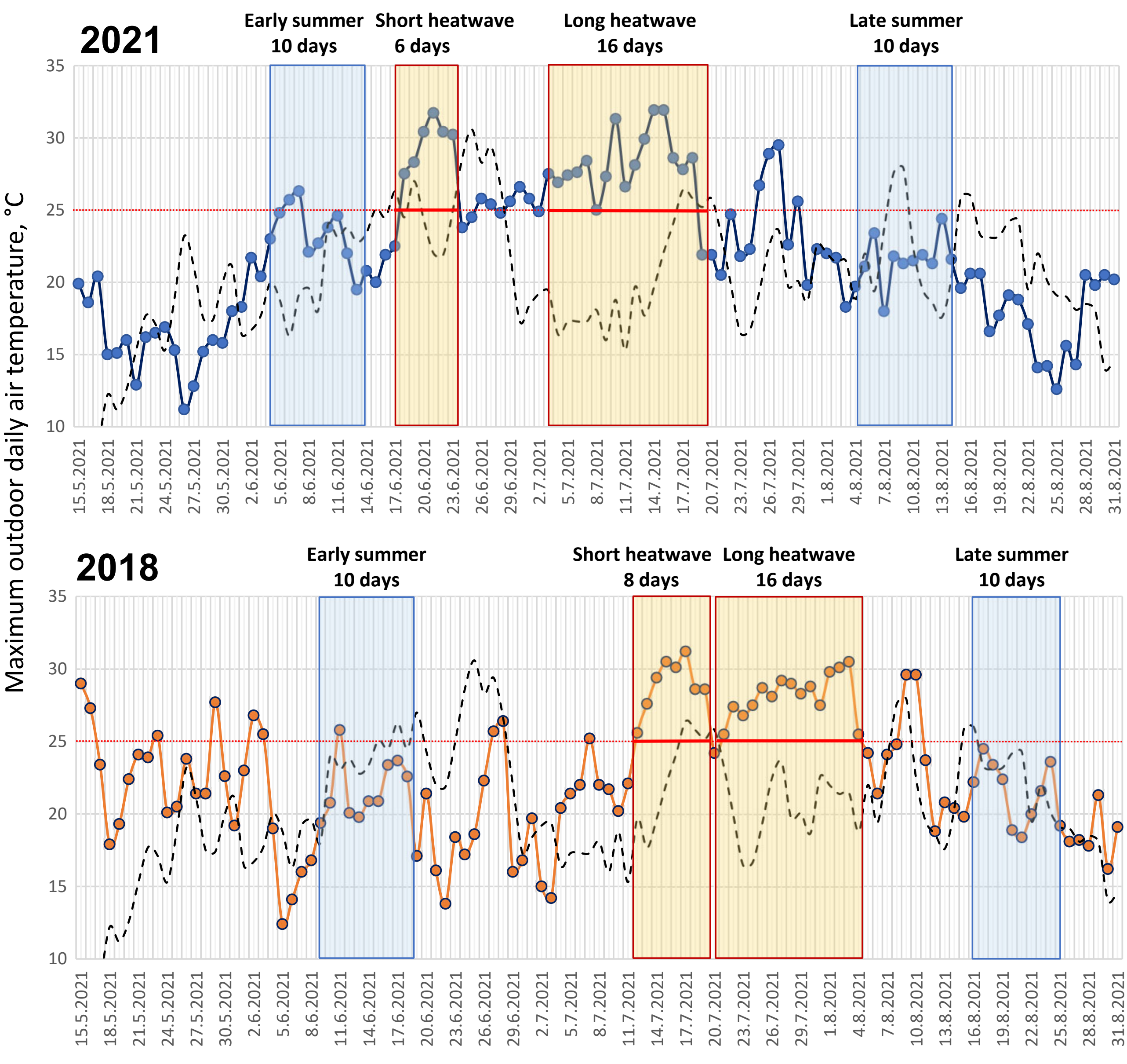


Figure 1. Daily maximum outdoor temperature distribution and the chosen four time periods in both years 2018 and 2021 and dashed line for 2020 average year.

In this study, 400 buildings with more than 2000 apartments in Helsinki were chosen for analysis, see **Fig.2**. In each building, from 3 to 6 apartments are equipped with indoor air temperature sensors.

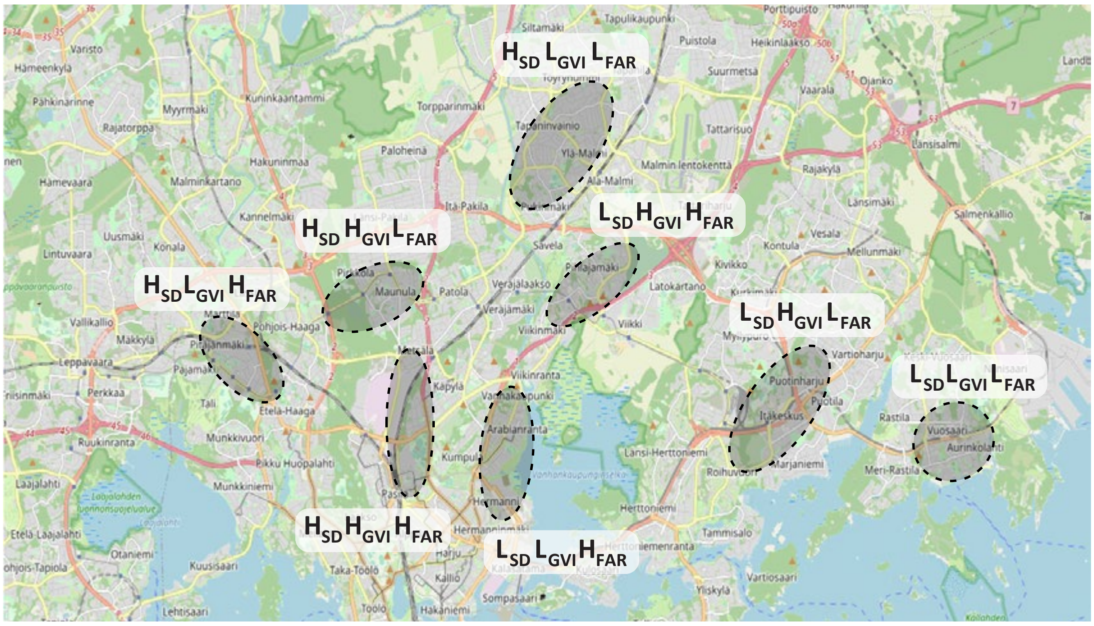
Based on the building's location, additional information about the local urban microenvironment was obtained based on open sources:

- Green view index (GVI) - the index describes the level of vegetation on the sides of the street, the shading of trees and surrounding buildings. Helsinki has on average a GVI of 50.

- Floor area ratio (FAR) - the index describes the urbanization of areas and is a combination of average built-up area and the height of the buildings. The data has a resolution of 100 meters by 100 meters, and the value of the FAR was calculated based on the nearest grid cell from the geometric centre of the building. The level of urbanization and building density is quite low in Helsinki corresponding to single-entrance 6-storey buildings for a square of 100 m by 100 m.

- Distance from the sea (SD) - this parameter reflects the effect of the seawater temperature.

After analysis of indexes, the lowest 25% of values were defined as a "Low" level of index, and the highest 25% were defined as "High". The buildings between "High" and "Low" were not used further in the analysis. Geographically closely located buildings were clustered with the same extreme (High or Low) indexes. These buildings then formed building groups, which on average represent the influence of the allocated combination of three selected urban parameters: GVI, FAR and SD. The building was grouped to neglect building characteristics (construction year, orientation etc.)



Acronyms Groups	Sea distance	Green view index	Floor area ratio	Number of buildings	Number of apartments
$H_{SD}H_{GVI}H_{FAR}$	High	High	High	29	112
$H_{SD}L_{GVI}L_{FAR}$	High	Low	Low	17	73
$H_{SD}H_{GVI}L_{FAR}$	High	High	Low	17	77
$L_{SD}H_{GVI}L_{FAR}$	Low	High	Low	18	91
$L_{SD}H_{GVI}H_{FAR}$	Low	High	High	19	102
$L_{SD}L_{GVI}H_{FAR}$	Low	Low	High	17	82
$H_{SD}L_{GVI}H_{FAR}$	High	Low	High	20	103
$L_{SD}L_{GVI}L_{FAR}$	Low	Low	Low	17	81

Figure 2. Geographical locations of the building groups that were clustered with green view index (GVI), sea distance (SD) and floor area ratio (FAR).

Whole summer

The effect of the urban microenvironment was analysed on the average indoor temperature during the whole summer. The temperature difference is shown to depict the relative performance of the factors, see **Fig.3 (a)**. The GVI and SD were dominant factors and FAR had a lower influence. The groups indoor temperature difference in **Fig.3 (a)** showed similar patterns of performance in 2018 and 2021 in most cases.

The maximum effect of the urban microenvironment was about 1.0°C between the coolest and warmest groups. The group with the lowest temperature had a high green view index (GVI), high sea distance (SD) and low floor area ratio (FAR). The group with the highest temperature had low GVI, low SD and high FRA, see **Fig.3 (b)**. The groups with low SD, high GVI and low FAR showed the best temperature-reducing abilities. Although the average effect was around 0.2°C, it was consistent throughout the whole summer period.

The GVI had the highest temperature-reducing factor due to the fact, that greenery in summer always provides shading for the buildings and surroundings and evapotranspiration combined with reducing short-wave radiation.

The sea distance e.g. sea temperature had more effect during 2021 due to the seawater temperature difference with high average summer air temperatures during that year.

Short and long heatwaves

In the early summer high GVI significantly reduced the temperature in the building groups during both years. The low SD had a lower temperature-reducing effect but was comparable to the high GVI effect during both years. The effect of low FAR varied in different years; the temperature reduced in 2018 and increased in 2021. The combination of FAR and GVI had a limited effect on the indoor air temperature. The combination of SD and GVI was predominant. The temperature difference between the best and worst-performing groups was substantial. The most likely reason for that is the influence of building thermal mass; nights were still cool and free cooling of ventilation with cool outdoor air and openable windows are able to cool room spaces.

During the first short heatwave, which happened in the middle of the summer, the low SD and the high GVI were the most significant temperatures. High GVI combined with a low FAR had a less significant effect.

The performance during long heatwaves showed that in 2018 the high GVI was the most temperature-reducing, due to the ability to mitigate shortwave radiation and the cooling effect of evapotranspiration regardless of high outdoor temperature. In 2021, the sea effect was high since the outdoor environment was not heated so much. The relative difference between groups was lowest among all time periods, as the thermal mass of the building was already warmed up.

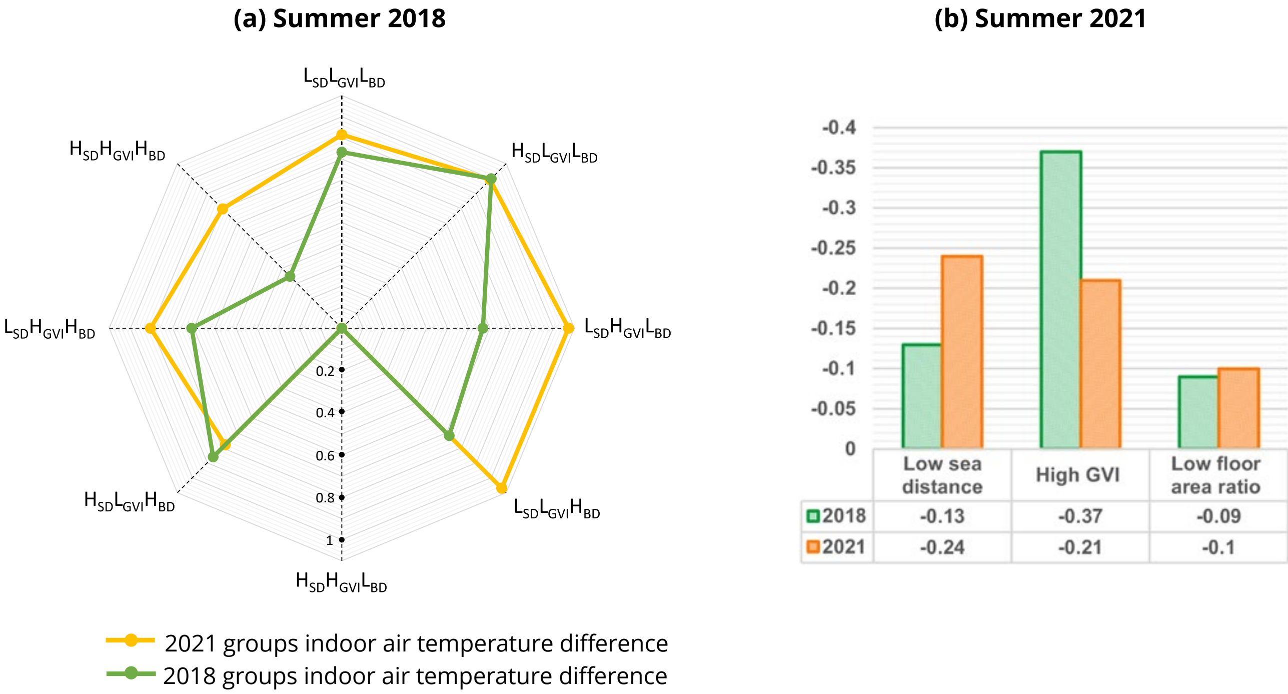
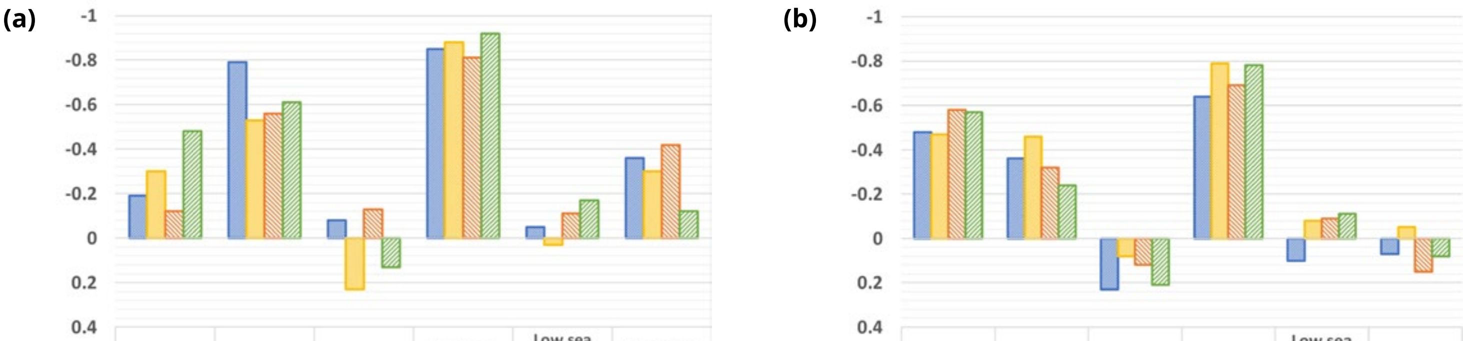


Figure 3. The relative and absolute differences in indoor air temperature between building groups during the whole summer **(a)**, the effect of individual microenvironment factors on indoor temperature in the whole summers of 2018 and 2021 **(b)**.



(a)	Low sea distance	High GVI	Low floor area ratio	Low sea distance : High GVI	Low sea distance : Low floor area ratio	High GVI : Low floor area ratio
Early summer	-0.19	-0.79	-0.08	-0.85	-0.05	-0.36
Short heatwave	-0.3	-0.53	0.23	-0.88	0.03	-0.3
Long heatwave	-0.12	-0.56	-0.13	-0.81	-0.11	-0.42
Late summer	-0.48	-0.61	0.13	-0.92	-0.17	-0.12

(b)	Low sea distance	High GVI	Low floor area ratio	Low sea distance : High GVI	Low sea distance : Low floor area ratio	High GVI : Low floor area ratio
Early summer	-0.48	-0.36	0.23	-0.64	0.1	0.07
Short heatwave	-0.47	-0.46	0.08	-0.79	-0.08	-0.05
Long heatwave	-0.58	-0.32	0.12	-0.69	-0.09	0.15
Late summer	-0.57	-0.24	0.21	-0.78	-0.11	0.08

Figure 4. The effect of microenvironment factors on indoor temperatures during different heat wave periods in 2018 **(a)** and 2021 **(b)**.

The low FAR reduced the temperature only with a combination of high GVI.

The group performance during the late summer was very similar to early summer, but the temperature difference between groups was higher due to nights already being colder.

Conclusions

Analysis revealed that long heatwaves significantly reduced the influence of urban microenvironment parameters and necessitated alternative approaches for passive or active cooling and urban parameters have a limited effect on indoor temperatures during the whole summer, but they can have a more significant role during shorter heatwaves. ■

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