



Climatic conditions and morphology – Correlation in urban squares

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Manuscript received May 15, 2025; revised July 12, 2025, accepted July 30, 2025

Abstract: Urban squares are the primary sufferers of climatic conditions, as they are most often created in dense urban areas. Their primary function is urban life – they provide a space for community events, and therefore many have an extensive paved surface. An important question is how their morphological characteristics, such as their spatial proportions, their enclosure, their openness, the quality of their surfaces, can influence and improve their outdoor thermal comfort [1].

Keywords: open space analysis, mitigation, climate adaptation, urban square morphology

1. Introduction

Climate change has led to an increase in the frequency of extreme weather events, particularly heatwaves. These events pose a significant health and quality of life threat to urban populations [2].

The urban heat island (UHI) effect has become a well-known and significant environmental issue on a global scale. It can be extrapolated from this that urban areas are characterized by the presence of built-up surfaces, such as asphalt, concrete, and buildings, which have the capacity to absorb and retain heat. The paved surfaces of the urban squares are warming up during the day and cooling down more slowly at night. It is evident that the urban areas experience significantly higher surface and air temperatures than the rural areas, particularly during the summer months and heatwaves. Urban heat islands present a range of challenges, including increased energy consumption, deteriorating air quality, health risks, and a decline in the quality of life [2–3].

However, it seems from the literature reviews that UHI is defined mainly for the urban tissue, but urban squares are not analysed specifically, even if they are in the focus of the urban life they serve as meeting places and they hold most of the services and functions of the city [4]. As urban squares are typically found in the central, densely built-up part of a city and are largely paved, they experience the most intense average temperature rise due to the urban heat island effect. There is high agreement that the role of urban design in local adaptation is essential and plays a central role in the adaptive response to climate change [5].

The objective of the present study is to examine the urban squares in Hungary, with a particular focus on the relationship between urban space morphology and climatic conditions. In addition, it is necessary to consider the following issues: firstly, which measures could be implemented in order to reduce these temperatures and transform them into a comfortable urban space.

The investigation focuses on the question of how the air circulation of morphologically different squares affects the thermal comfort of the spaces and the perception of temperature experienced by individuals.

In addition to the measurement of various climatic factors, consideration must be given to the concept of outdoor thermal comfort (OTC), which can be defined as the subjective perception of the temperature experienced by individuals [1].

Wind speed, microclimatic conditions, wind comfort, and heat stress can provide good guidelines for measuring outdoor thermal comfort. The scientific background to this is presented below.

A prominent expert in the field of wind and airflow research was Alan G. Davenport, who studied wind effects on buildings and urban environments. Davenport significantly advanced wind tunnel experimentation by developing precise measurement techniques for studying airflow and wind loads around buildings. His work improved the accuracy and reliability of wind data analysis, enabling better prediction of wind variations in design processes [6]. Davenport's seminal contributions to the field of pedestrian comfort criteria have profoundly influenced contemporary urban planning practices, underscoring the enduring significance of his research [7].

Trevor V. Lawson, a researcher at the University of Bristol, has also developed important pedestrian wind comfort criteria. Davenport's and Lawson's pedestrian wind comfort scales are both utilized to assess wind effects around buildings. Both scales impose stringent restrictions within the designated sitting and waiting zones. The Lawson scale is a valuable tool that should be incorporated into urban planning, land use design, and the assessment of comfort levels [8].

A substantial body of research has been dedicated to investigating the alterations in urban climate and the development of strategies to mitigate the impact of heat waves in urban environments in the context of climate change. Prior to the present

studies, research efforts were directed towards the analysis of urban wind patterns and the phenomenon of surface temperature change.

A study was conducted to investigate the impact of tall buildings on airflow in street canyons and their effects on pedestrian comfort and safety. Focusing on wind behaviour between parallel high-rises, they found that building configuration and street canyon geometry significantly influence wind speed and direction at pedestrian level. Appropriate architectural and urban design has been demonstrated to mitigate strong gusts, enhance natural ventilation, and improve the microclimate [9].

A study with a similar theme examined pedestrian-level wind speeds in urban street canyons, focusing on how “void decks” – open ground-floor spaces – affect airflow. The study examined the impact of void deck height and the canyon H/W ratio on wind speed, emphasizing how such characteristics can enhance airflow, pedestrian comfort, and the urban microclimate [10].

Microclimate analysis involves studying the climatic conditions created by the shapes of urban spaces on a small scale. The temperature of an environment affects the survival of living organisms, and this is a very important factor in today’s human environment.

A plethora of scientific sources exist that address the subject of heat stress, encompassing various aspects such as its effects on human health and safety. The topic is based on the research of A. P. Gagge et al. on the relationship between heat sensation, thermal comfort, and human physiological responses at different ambient temperatures. The authors of the study determined that comfort, thermal neutrality, and the perception of “comfortable” fall within the 28–30 °C range, where the body’s thermoregulatory mechanisms are inactive, resulting in the absence of sweating or vasoconstriction/expansion [11].

Subsequent research has examined the impact of urban form – defined as the configuration of buildings, their height, and the design of streets – on pedestrian comfort. The research focuses on how wind speed and direction vary in urban spaces and how these can be deliberately shaped to achieve comfortable and safe wind conditions in urban spaces [12–13]. Improving urban wind comfort not only benefits individual pedestrians but also contributes to a more active use of public spaces and increased energy efficiency [13].

Climate change can cause daily maximum and minimum temperatures to fluctuate more widely, resulting in changes to the impact on users of the space, with extremes leading to greater stress.

The aim of the research is to study the morphology and urban climate of historical Hungarian squares, typically the main squares.

The evolution of Hungarian city main squares can be categorized into two distinct periods: the development of medieval cities and the urban development era that commenced in the 19th century [14]. After these two intensive periods

mentionable is the socialist and modern era which has created new towns with urban squares, but they represent a very different typology [15].

Typically, squares are grouped according to morphological criteria [16–17]. The present study classifies urban squares into 11 groups based on a spatial focus analysis.

2. Materials and methods

The research is based on the morphological grouping of Hungarian squares previously studied by Anna Szövényi in the framework of the Hungarian Academy of Arts Scholarship Programme. The present research investigates the relationship between the morphology of squares and urban climate.

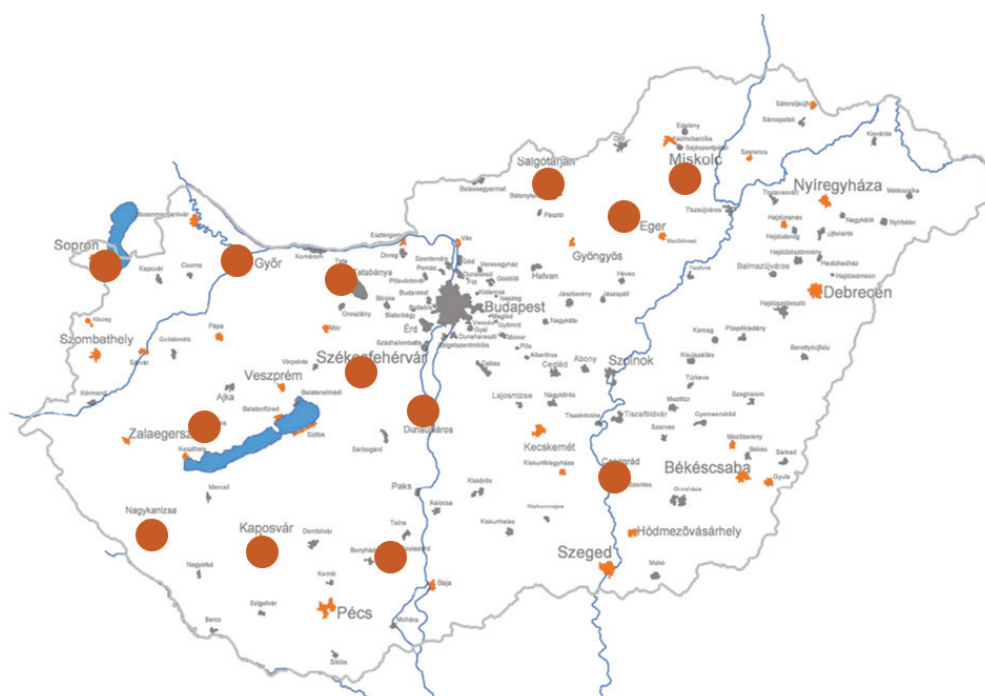


Figure 1. Location of the main urban squares studied within Hungary

This research seeks to answer the following questions:

- What are the morphological characteristics that most influence the urban squares' climatic conditions?
- What are the most effective ways to improve these conditions?

The method of investigation is the urban climatic analysis of each (morphologically distinct) square type by comparing the values of surface temperature, shade, wind, and ventilation using a 3D model.

The previous morphological grouping distinguished 11 groups. Some of the morphological categories (inclined squares and thematic focused squares) did not appear to be relevant based on the tests, or the capabilities of the software used did not allow for differences to be detected.

Table 1. The studied squares and their basic data

Name /Features	Morphology	Area (m ²)	Latitude (m)	Length (m)	Facades' av. height (m)	Av. ratio
Székesfehérvár, Szent István Square	triangular	6,500	55	126	12	1:3
Tata, Kossuth Square	triangular	7,400	50-70	150	14	1:3
Szentes, Kossuth Square & Erzsébet Square	composite	900	(140, 120)	(120, 84)	15, 12	1:1, 1:2
Keszthely	giant	12,000	90	130	12	1:2
Nagykanizsa	giant		93	274	10	1:3
Székesfehérvár, Hősök Square	small	710	19	30	12	1:2
Győr, Széchenyi Square	square-shaped	6,200	79	79	13	1:1
Eger, Dobó Square	rectangular	7,200	60	120	15	1:4-1:10
Sopron, Széchenyi Square	rectangular	11,600	55	200	12	1:4
Miskolc, Városház Square	longitudinal	6,600	286	24	11	1:10
Szekszárd, Béla király Square	towered	18,500	90-60	150	12	1:6-1:10
Kaposvár, Kossuth Square	towered	6,500	27-50	90	13	1:3
Dunaújváros, Main Square	modern	7,800	63	119	20	1:2
Salgótarján, Main Square	modern	16,000	100	140	15	1:1,5

The methodology was to build 3D models of the squares and then run climatic analyses. The spaces were modelled by building the square walls; the buildings are represented in the figures with their mass models. The areas have been defined by the façades and form the basis of the investigations. Due to the areas' different

sizes, the most suitable comparison data series can be obtained using height-to-width ratios.

For the climate analysis, we chose to use Autocad FORMA software, and we used the program's wind and microclimate analysis tools for our research into existing urban main squares.

AutoCAD Forma is part of Autodesk's cloud-based architecture and urban design platform. In research and education, we make the most of the program's user-friendly nature, which enables it to cover a wider area and urban context by making use of existing 3D models. It performs site analysis (wind, daylight, noise, views, etc.) to support smarter design decisions from the concept stage. The software can link models to geographical locations and apply meteorological data at scale.

The comparisons were based on the following analyses of the Forma programme: the number of hours of sunshine on 15 February and 15 July, the Davenport and Lawson wind comfort models [5], and a microclimate analysis at the two extremes.

The wind comfort analysis includes assessment of the area as suitable for sitting/standing/walking or uncomfortable for users.

Wind flows are visually represented in 3D, showing areas of high or low wind speed and turbulence, which is useful for identifying potential problem zones, such as wind tunnels or uncomfortable outdoor areas. Different massing options can be quickly compared to see how design changes affect wind performance. Wind analysis in Forma provides quantitative feedback such as wind comfort ratings based on Lawson and Davenport criteria.

The microclimate analysis includes delimiting the areas affected by heat stress and determining its proportions in space (mild or strong), as well as identifying temperature extremes.

The research uses these three variables to analyse the climatic conditions of the spaces. It results from this that the reduction of summer heat stress can be best modelled using the capabilities of the software. Although the data will not be accurate due to the lack of green areas, the differences are still well represented.¹

In most cases, the aim was to distribute the wind over the surface, with the additional possibility of opening up new ventilation directions by openings. The third target in achieving cooling was to increase the shaded areas.

The tools used to achieve this were as follows:

Wind deflection:

- by directing and rearranging groups of trees,
- distributing the wind by inserting pavilions and public space elements,

1 Testing capabilities and limitations of Autodesk form software: The software used explicitly accounts for the morphology of the squares, representing vegetation only as rows of trees in groups of trees, and it does not account for green surfaces or the quality, material, and colour of any surfaces. However, the surface temperature, microclimate, and wind conditions of each square can be shown.

- creating new ventilation routes by openings;

Increasing shaded areas:

- installation of clusters of trees or other objects,
- increasing the height of square walls.

3. Results and discussions

The research examined 14 squares in their current and modified states. These squares represent nine of the eleven morphological types typical of historic squares in Hungary.

The analysis shows that the physical parameters impacting wind movement and microclimate are the aspect ratio and height of the space walls.

Open spaces with an aspect ratio greater than 1:3 are more exposed to thermal stress. Wind movement is more noticeable and affects thermal sensation depending on the geometry of the space. In spaces with an aspect ratio of less than 1:2, heat stress generally affects a smaller surface area, and the shading effect of the walls significantly improves the microclimate. However, in terms of wind movement, it can be observed that the wind blows over buildings and does not ventilate the space. Strong wind speeds in narrow spaces (e.g. streets with paved areas or street-level rows) cause the greatest loss of wind comfort.

The average height of square walls is similar for historic squares, ranging from 12 to 15 metres, with taller buildings only appearing in modern 20th-century squares. Here, tall buildings cause wind turbulence, which significantly impacts the perception of wind comfort.

The test results show that the public squares assessed were generally comfortable for short-term outdoor use, with standing and strolling being the most supported activities. Sopron's Széchenyi Square had the highest level of wind comfort for sitting (65%), while Eger's Dobó Square and Salgótarján's Main Square had over 80% suitability for standing. Nagykanizsa was the only square with a notable level of discomfort (10%), and very few locations were suitable for walking. Overall, discomfort was minimal across most sites, suggesting that wind conditions in Hungarian public squares are generally tolerable.

Most squares experienced moderate to high levels of heat stress during the summer months. Szentes, Kaposvár, and Eger showed the highest levels of heat stress, Keszthely and Tata fared better, with a higher proportion of moderate than high heat stress. Szent István Square in Székesfehérvár recorded the highest maximum temperature of 36 °C, while the minimum dropped to 15 °C, indicating a significant thermal range. Overall, urban heat is a significant issue in these areas, with few places offering comfortable thermal conditions in summer.

In summary, most squares experience high heat stress with limited relief from the summer heat, making some spaces uncomfortable for long stays. These results

highlight the need for improved microclimate design to mitigate heat and wind discomfort in public squares throughout the region. The detailed results for wind comfort and microclimate data are presented in *tables 3–4* of the *Annex*.

Due to space limitations, this article only presents the most significant results of the research, which relate to the following four morphological groups of spaces: giant, small, rectangular, and modern.

Table 2. Results of the wind comfort assessment of the presented examples of giant, small, rectangular, and modern squares

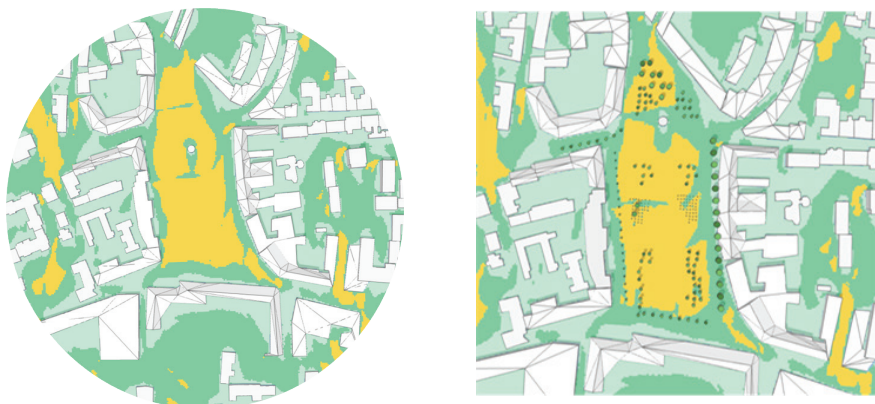
Squares/wind comfort	Suitable for sitting (%)	Standing (%)	Strolling (%)	Walking (%)	Uncomfortable (%)
Nagykanizsa <i>Erzsébet square</i>	36	46	18	0.1	10
Székesfehérvár, Hősök Square	14	54.8	30.1	1.1	0
Sopron, Széchenyi Square	65	35	0	0	0
Salgótarján, Main Square	15.4	80.4	3.2	0	0

The huge market square in Nagykanizsa exhibits the characteristics of a giant square, with significant wind streams only generated at the narrowest points in the corners. The walls are also low relative to the size of the square, with an h/w ratio of over 1:6.

One attempted modification was to raise the west field wall to cool the space. Another modification was to increase the density of the tree groups. Together, these two actions improved the microclimate, with the largest, 10% difference occurring in the medium-acceptable area (*Figure 2*).

Of all the squares included in the research, only Hősök tere (Heroes' Square) in Székesfehérvár was *small* – in terms of morphology type. Measuring only 720 m², the square has an aspect ratio of less than 1:2. Climate tests on the enclosed, small square showed that while the space is very pleasant in terms of wind comfort and largely suitable for seating, there is no ventilation, and summer warming is not reduced by wind movement. The heat stress values in the space are not extreme (24%), and moderate heat stress (73%) and extreme values do not significantly exceed the outdoor thermal comfort classification (highest temperature: 32 °C; lowest temperature: 25 °C) (*Figure 3*).

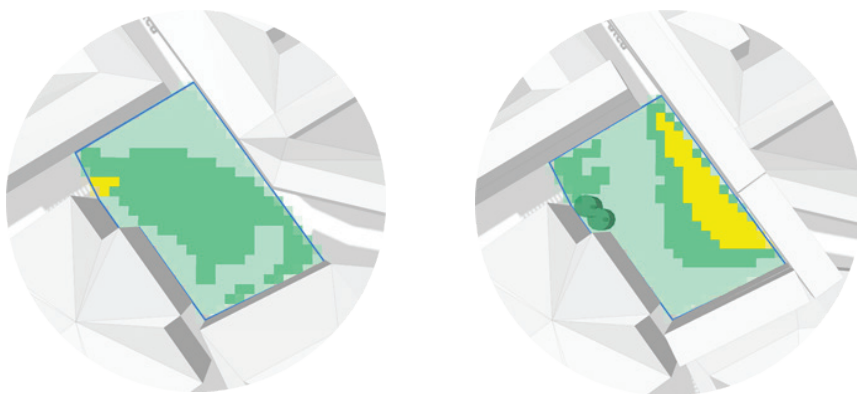
The climatic conditions of the space could not be significantly altered by interventions such as raising the space wall, fencing it off, and opening it up, as these had little effect on the edge values, even though spatial representation varied.



Current state

Modified state

Figure 2. Changes in wind comfort due to modifications in Nagykanizsa, Erzsébet square



Current state

Modified state

Figure 3. Changes in wind comfort due to modifications in Székesfehérvár

The most significant impact has been caused by interventions in *rectangular squares* that disrupt the walls, as illustrated in *Figure 4*. For an aspect ratio of 1:3 to 1:4, changes to the square walls result in a noticeable change to 30–40% of the space, as well as a significant reduction in measurable thermal stress.

Modern squares show the least measurable change in microclimate and wind conditions. The significant increase in the volume of the building walls and demolition of the square walls in Salgótarján had only a minor impact on wind comfort and heat stress percentages. Increasing the height of the building by 6 meters and adding arcading reduced wind speed. Changes to the surface comfort

of the square: increase in seating area: +10.9%, decrease in standing area: -9.2%. Suitable seating areas were created on the square.

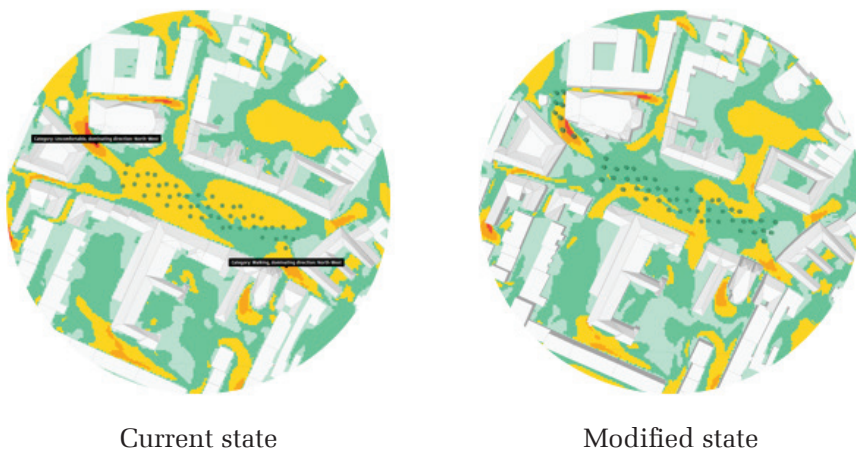


Figure 4. Changes in wind comfort due to modifications in Sopron Széchenyi square

4. Conclusions

The spatial mapping of the climatic characteristics of the different types of urban squares provides an opportunity to identify the points of intervention and to identify common and different actions.

Morphological groups react differently to wind effects: triangular squares experience increasing wind speeds at their shorter ends; square-shaped squares experience increasing wind speeds towards their corners; buildings in the middle of squares experience different wind conditions. The shape and aspect ratio determine the climatic baseline of the main square, which can be modified by vegetation and surface qualities.

The analysed interventions, modifications affect the wind and microclimate of the spaces in different ways.

- Opening up groups of trees, including wind tunnels, proved to be a suitable tool to divert the wind, thus reducing the surface temperature of the square.
- The combination of elements, pavilions, and trees in the space allowed the unfavourable north-westerly draught to be dispersed. The distribution of the ventilation has resulted in visible cooling on the (space) surface. The opening of the space walls resulted in the initiation of air flows in several squares and had a positive effect on the cooling of the surfaces of the squares.

- Raising the height of the space walls showed a reduction in surface temperature, but improving the air-space ratio in Hungarian spaces can only be achieved by a significant increase in height, which can only be applied in parts at most due to the historic buildings.

The research shows that, once spaces have been grouped morphologically; types of effective intervention can be identified to optimize wind comfort. These microclimatic interventions modify the wind effect and contribute to improving thermal comfort.

The selection of appropriate software can facilitate the identification of optimal thermal comfort within residential environments by methodically evaluating each climatic factor.

Acknowledgements

The research involved students from the Department of Urban Planning and Urban Green Infrastructure in the courses Urban Planning and Design and Urban Square Analysis.

The research is based on the morphological grouping of Hungarian squares previously studied by Anna Szövényi in the framework of the Hungarian Academy of Arts Scholarship Programme.

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Annex

Table 3. Results of the wind comfort assessment of squares

Squares/wind comfort	Suitable for sitting (%)	Suitable for standing (%)	Suitable for strolling (%)	Suitable for walking (%)	Uncomfortable (%)
Székesfehérvár, Szent István Square	26	53	97	22	0
Tata, Kossuth Square	23.5	67	13	0	0
Szentes, Kossuth Square & Erzsébet Square	21.6	69.3	9	0	0

Squares/wind comfort	Suitable for sitting (%)	Suitable for standing (%)	Suitable for strolling (%)	Suitable for walking (%)	Uncomfortable (%)
Keszthely	38	38	21.8	2.2	0
Nagykanizsa	36	46	18	0.1	10
Székesfehérvár, Hősök Square	14	54.8	30.1	1.1	0
Győr, Széchenyi Square	13.2	40.6	38.9	6.7	0.7
Eger, Dobó Square	19	80	1	0	0
Sopron, Széchenyi Square	65	35	0	0	0
Miskolc, Városház Square	39	60	1	0	0
Szekszárd, Béla király Square	11.1	73.9	15	0	0
Kaposvár, Kossuth Square	9.7	66	24.3	0	0
Dunaújváros	11.7	48	39.6	0.7	0
Salgótarján, Main Square	15.4	80.4	3.2	0	0

Table 4. Results of the microclimate assessment of squares in summer heat

Squares/wind comfort	No heat stress (%)	Mild heat stress (%)	High heat stress (%)	Max. temp (°C)	Min. temp (°C)
Székesfehérvár, Szent István Square	0	35	65	36	15
Tata, Kossuth Square	7	54	39	33	25
Szentés, Kossuth Square & Erzsébet Square	0	26	74	35	26
Keszthely	8	80	12	34	21
Nagykanizsa	10	67	49	30	28
Székesfehérvár, Hősök Square	9	73	18	32	24
Győr, Széchenyi Square	2	56	42	34	28
Eger, Dobó Square	0	12	88.4	35	30
Sopron, Széchenyi Square	1	77	22	32	28

Squares/wind comfort	No heat stress (%)	Mild heat stress (%)	High heat stress (%)	Max. temp (°C)	Min. temp (°C)
Miskolc, Városház Square	1	57	43	33	28
Szekszárd, Béla király Square	4	71	25	35	27
Kaposvár, Kossuth Square	0	30	70	33	28
Dunaújváros	1	71	28	33	23
Salgótarján, Main Square	2	93	5	32	27

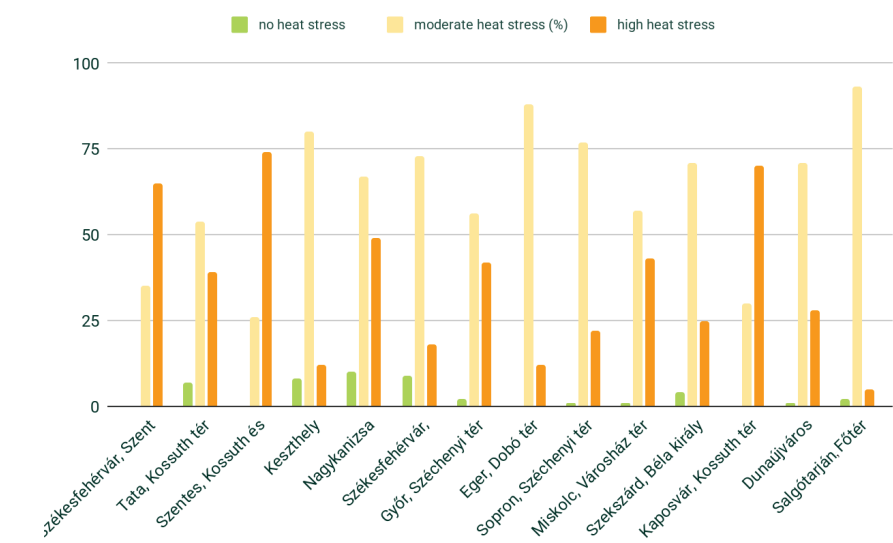


Figure 5. Results of the heat stress assessment of squares