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# Introducing an Optimal Model and Dimensions of Lightweight Membrane Canopy for Hot and Dry Climate of City of Semnan in Iran

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**Abstract**

In urban open spaces, especially in large cities with warm climates, the users experience high thermal loads, which cause thermal discomfort. The thermal comfort in open spaces can be improved by shading. The problem is shading and protecting the open spaces from stresses caused by overheating of the earth's surface and the environment. The importance of shade and reducing radiation in achieving thermal comfort in open urban spaces is to increase the human presence, create a climate change, and increase the comfort conditions. Recognizing the factors that create shadows such as canopies and their characteristics can create a favorable space in order to enjoy the abilities of the outdoor space. New membranes have many characteristics of nomadic tents, and due to the creation of shade and natural ventilation, are very suitable for the areas with hot climates. Introducing an optimal model and the dimensions of a lightweight membrane canopy can create the outdoor thermal comfort, and increase the efficiency of the outdoor spaces. In this work, the library, field, and simulation studies are used. According to the field studies, the presence of membrane canopy can cause the temperature differences of up to 7.8 $^{o}$C. The simulation results with Ansys, ENVI-met, and Ladybug plugin show that the membrane canopy cools the space below, and prevents overheating. Among the four canopy models, the saddle canopy is suitable with a 40.63% impact on the environment, and creates a cooler space under the canopy. Therefore, a lightweight saddle membrane canopy with dimensions of 5*5 square meters and a useful height of 3 m is introduced as a suitable model of membrane canopy for the hot climate of the city of Semnan in Iran.

**Keywords:** *Membrane structure, Canopy, Outdoor thermal comfort, Semnan city, Energy softwares.*

## 1. Introduction

One of the most important factors that affect the human comfort and health is weather conditions [1], which is one of the most important factors controlling the daily and long-term activities of the human life [2]. Comfort conditions are a set of conditions that are thermally suitable for at least 80% of people, and people do not feel cold or hot in those conditions [3]. The main variables of the outdoor thermal comfort include the climatic and individual variables. Climatic variables include air temperature, airflow, relative humidity, and radiant temperature (MRT) [4]. Solar radiation can be considered as the most important meteorological parameter that affects all the climatological and biological processes [5].

In open spaces, the level of thermal comfort can be affected by the factors such as the surface materials, presence of canopies, use of green spaces, and waterfalls in the area [6].

Shade plays an important role in designing the pedestrian-friendly outdoor spaces in hot desert cities, and also decreases the environmental temperature [7]. The shading design reduces the direct shortwave radiation, which reaches the ground or building envelopes and plays a positive role in improving the outdoor thermal environments [8-11]. Shading in urban spaces by any means is of utmost priority, particularly between 12:00 h and 15:00 h, and preferably between 10:30 h and 15:30 h, and people tend to amass in the shaded spaces in warm conditions [12].

He and Hoyano have studied the thermal properties under membrane structures by the field study and simulation with CFD, founding that the solar transmission is one of the key factors affecting the thermal environment in the living space under the membrane structure, and the membranes can reduce the air temperature [13, 14]. Some other researches have shown that shading effectively lowers the thermal stress and decreases the temperature during the winter and summer [15-17]. There is a significant temperature difference between the outdoor space and the semi-outdoor space under the membrane structure. Therefore, it can be said that the use of the tensile structure in the semi-outdoor space has enabled the temperature change [18].

Today, the usage of canopies in public spaces is widespread; however, only a few of them can produce a desired biological result. As one of the components that provide comfort for the users, canopy leads to an increase in the time of people in the environment, dealing with the adverse weather conditions and the possibility of enjoying the view. In the hot and dry climates, due to high heat, the presence of clear sky, intense sunlight, thermal comfort conditions in outdoor spaces are limited. In this climate, the outdoor spaces can be used for a limited time but by controlling the temperature and creating shade in the outdoor spaces, the comfort conditions can be provided.

Therefore, the details of a canopy design such as the canopy model and dimensions in such spaces are the factors that should be paid special attention by the designers. Consequently, in this work, the effect of lightweight membrane canopy on creating the outdoor thermal comfort in the hot and dry climate of the city of Semnan is studied using the library, field, and simulation studies, which introduce the optimal model and dimensions of lightweight membrane canopy.

## 2. Membrane canopy

Membrane structures are very thin and flexible with a tensile membrane stiffness [19]. Using this type of structure can be due to its high structural efficiency such as large opening or lightweight [20]. The membrane canopies are the primary forms of roofing, which have been used to make the traditional forms for thousands of years. Fabric membranes act as both the structure and coating, and reduce the weight, cost, and environmental effects [21]. The coating of most architectural membrane materials offers a high reflection to solar radiation (typically between 65% and 80%), and this can be exploited for an effective shading of the covered space. Together with their ability to cover large spaces with minimal means, the membrane structures are particularly suitable for the shading applications. The spanning of large spaces as well as the presence of high points to achieve the desired double-curvature of the membrane skin almost inevitably lead to very large undivided volumes of air. Substantial internal ceiling heights favor the accumulation of buoyant warm air at the high points of the structure resulting in the formation of cooler layers of air in the lower/occupied zones. [22].

Form diversity is one of the main characteristics of the tensile membrane structures. In a membrane structure design, the membrane form is a part of the structural and load-bearing system. The membranes can take various forms such as single-curved, synclastic, and anticlastic. Fri Otto has also divided the membrane structures into groups based on the shape or type of supports. These classifications are anticlastic or saddle, wavy, arched, and conical [23].

According to the standards, the height of a person in a standing position is 1.75 m, and in the case of raising arms is 2.25 m, which is considered as a basis for the height below the canopy in order to prevent the human manipulation of the canopy and its structure. Considering that in open urban spaces, especially in neighborhood parks, people are present as a family and often with their children is necessary. Therefore, it is better to consider other elevations for the human beings; for example, the height of a father who puts his child on his shoulders. Considering these cases makes the family more satisfied with being in that urban spaces. Therefore, the height of a person with a child on his shoulders is calculated to be 3 m. This number is the maximum value of human height, and other heights for the pedestrians will be less than this number. According to the simulation results, a lower height of the canopy causes a better performance. The higher height of the structure in the environment may create favorable comfort conditions but the economical height of the structure has also been considered in this work.

## 3. Methodology

Due to the nature of this work and the hypothesis, the research studies are conducted in the form of libraries, fields, and also the study of canopy parameters using the simulation software. More precisely and in detail, the research work is performed in the following steps:

a) The library studies are conducted using the sources and documents in order to identify, compile studies, and analyze the Persian and non-Persian sources in the field of outdoor thermal comfort and flexible membrane structures.
b) In order to measure and investigate the effect of shade, the field studies are

performed by measuring the climatic parameters in several canopies in the hot and dry climate of Semnan because the purpose of a membrane canopy design is to create the thermal comfort in urban spaces (neighborhood park) located in hot and dry climates. It should be noted that in the city of Semnan, no field research work has been done on canopies.

c) The simulation was done using the Ansys, ENVI-met, Grasshopper (Ladybug plugin), and Revit softwares. In the Ansys software, several common canopy models are simulated and in ENVI-met, Ladybug, and Revit the dimensions and height of canopies are simulated and examined. Then based the on dimension change (plan and height), the extent of their effect on the thermal comfort is considered.

d) The design is performed using the analysis and categorization of the results of the field studies and simulations. Finally, the appropriate dimensions and model of the lightweight membrane canopy are introduced.

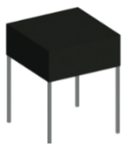
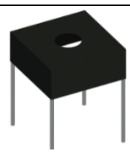
## 4. Semnan

The city of Semnan is located in the geographical position of (53°23′ E, 35°33′ N) and its altitude is 1138 meters above sea level. Prolonged dry heat and intense temperature difference between winter and summer and the intense difference between the day and night temperatures are the climatic features of hot and dry climate [24]. The climate of Semnan is hot, and dry and low rainy in the summer and moderate in the other seasons. July, August, September, and June are the hottest months in Semnan, and have the sunniest hours. The temperature range and humidity changes in Semnan during the year are very high so that the thermal conditions in winter are very far from the lower limit of the comfort zone, and the thermal conditions in the summer are far from the upper limit of the comfort zone. Also the months of April and October are in the comfort zone, the months of November, December, January, February, and March are below the comfort zone, and the months of May, June, July, August, and September are above the comfort zone [25].

## 5. Field studies

Field studies were conducted in order to investigate the effect of lightweight membrane canopy on reducing the outdoor temperature in the open space of Semnan with a hot and dry climate. Canopies are according to Table 1. The data was collected in the summer in each canopy for one week with two devices. One was installed as a reference device in the open air, which reflected the climatic conditions, and the other device was installed under the canopies in order to identify the thermal conditions. The results obtained showed that a lightweight membrane canopy with dimensions of about one m (1.2*1.2 square meters) could reduce the air temperature under the canopy up to 7.8 degrees Celsius (18%). The addition of a central hole in the canopy also caused heat and moisture to escape but at certain times of the day, the temperature rose due to direct sunlight. This problem could be solved by considering a lid for a hole that prevented the sun's rays from entering and did not prevent the air from leaving.

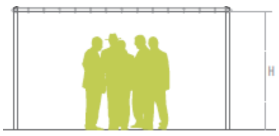
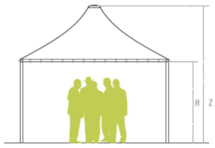
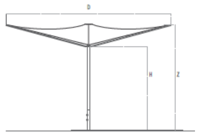
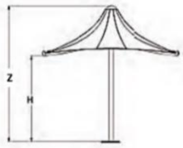
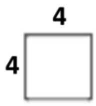
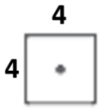
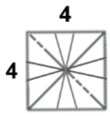
**Table 1. Comparison table of canopies.**

| Canopy | Type 1 | Type 2 | Type 3 |
|---|---|---|---|
| | **Simple canopy** | **Simple canopy with a 50 cm edge** | **Simple canopy with a 50 cm edge and central hole** |
| Picture |  |  |  |
| The most temperature difference | 5.5 C | 7.8 C | 6.1C |
| Hour | 12 | 16 | 9 |
| Impact percentage | 12% | 18% | 16% |
| The most relative humidity difference | 4.9 | 3.9 | 1.4 |
| Hour | 7 | 7 | 6 |
| Impact percentage | 14% | 11% | 4% |

## 6. Simulation in Ansys Fluent software

There are various canopies including wavy, plain, arched, conical, inverted conical, umbrella, saddle, etc. Four common canopy models with the specifications in table 2 were selected for simulation with the Ansys software. The membrane of canopies was made of fabric, and their structure was considered to be metallic. The effective height and overall dimensions of the canopies were the same in all cases. The simulation was performed for one of the hottest days of summer in mid-July with an ambient temperature of 40 degrees Celsius and a static flow mode.

**Table 2. Comparison table of canopies.**

| Canopy | Simple canopy | Conical canopy | Saddle canopy | Umbrella canopy |
|---|---|---|---|---|
| Picture |  |  |  |  |
| Dimensions |  4×4 |  4×4 |  4×4 |  4×4 |
| Overall height of canopy (Z) | 2.70 m | 4.30 m | 3.30 m | 4.50 m |
| Useful height under the canopy (H) | 2.70 m | | | |

The earth temperature distribution around the canopies is shown in figure 1. The orange color indicates the earth with a temperature of 80 degrees without a canopy. Considering the comparison of the earth temperature distribution around the canopies, it can be seen that the ground surface temperature around the saddle canopy is reduced in a wider range than the other canopies. The solar radiant flux is 650 W/m$^2$, and the air temperature is 40 degrees Celsius, which means that the flat earth temperature without a canopy will reach 80 degrees Celsius.

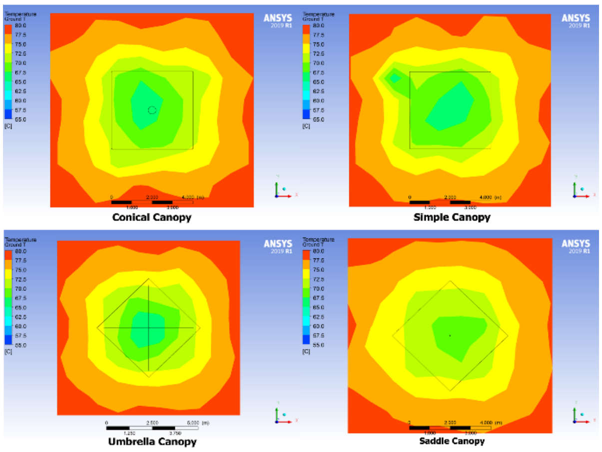



**Figure 1. Earth temperature distribution around canopies.**

The air temperature distribution around each one of the canopies is shown in figure 2. A conical canopy is better than a simple canopy because the temperature under a simple canopy is slightly higher. However, in the conical canopy, due to the high height of the roof, the temperature is slightly lower than the simple canopy, and due to the curvature of the upper surface, hot air can escape more easily; hot air collects at the upper point, and if a hole is created at that point, hot air escapes from the top of the canopy due to the stack effect. Also the umbrella canopy is better than the saddle canopy because the air temperature under the saddle canopy is higher than the umbrella canopy. In general, an umbrella canopy affects a wider range.

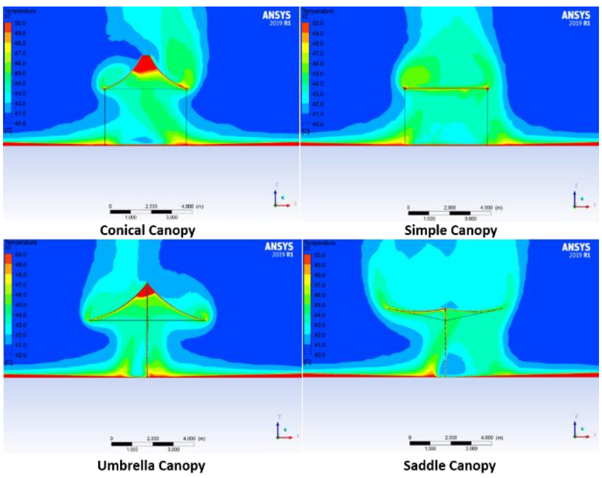



**Figure 2. Air temperature distribution around canopies.**

Figure 3 shows the air velocity contour around the canopies. The airflow velocity under the simple canopy is slower than the other canopies with curved roof. Locally, the airflow speed created under the canopy is higher for the saddle model, and the reason can be more trapped air under the umbrella and conical canopies than saddle canopy. In the conical and umbrella canopies, the air flow velocity is lower in the upper part of the canopy and is higher in the lower part of it. In the saddle canopy, air flow velocity is faster than the others.

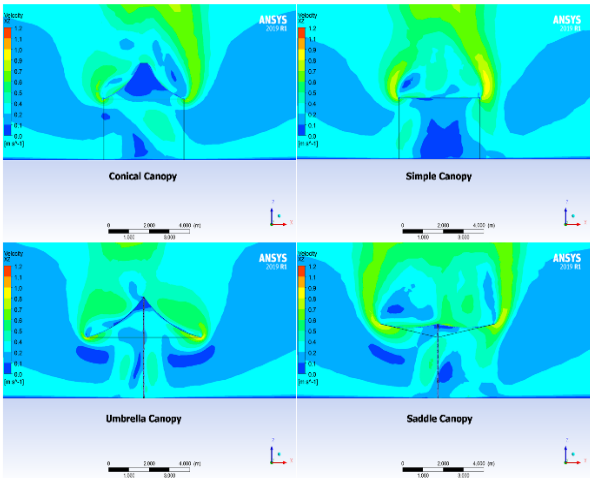



**Figure 3. Air velocity contour around the canopies.**

Table 3 shows the general results of the Ansys simulation for each canopy.

In the real-world data collection, the temperature under the canopy was lower than the environment temperature but in the simulation results, the output temperatures in each case were higher than the environmental inlet temperature (40 °C). The reason is that in the real conditions there is wind but in the present simulation, the wind is not applied, and it is assumed that the environment fluid does not have velocity (static flow mode), and there is only a natural displacement. There are no objects, trees or anything around canopies in the simulation, and the flat surface absorbs heat strongly; but in reality, there are other objects around the canopy that reduce the intensity of the heat. The canopy does not cool the ground but prevents overheating. In the present simulation, the ground around the canopy is heated up to 70 to 80 degrees but it is cooler under the canopy.

## 7. Simulation in ENVI-met software

For the simulation in ENVI-met, the location of Semnan was determined. August 12th, 2020 was selected as one of the hottest days of summer for simulation. The climatic parameters such as the maximum and minimum air temperature, maximum and minimum relative humidity, wind speed, and direction for August 12, 2020 were used as the inputs in ENVI-met. In ENVI-met, the canopies with dimensions of 1×1, 2×2, 3×3, 4×4, 5×5, and 6×6 square meters with a useful height of 2.70 m were simulated separately. The outputs are for noon.

The simulation results of the canopies with dimensions of 1×1, 2×2, and 3×3 square meters with a height of 2.70 m at the height of 1.5 m below the canopy are shown in table 4 and figures 4 and 5. The simulation in the canopies continued up to 6×6 square meters but due to the similarity of the results, only the simulation results up to 3×3 were reported.

**Table 3. Comparison table of canopies.**

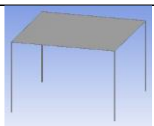
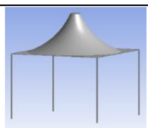
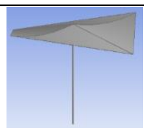
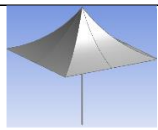
| Canopy | Simple canopy | Conical canopy | Saddle canopy | Umbrella canopy |
|---|---|---|---|---|
| Picture |  |  |  |  |
| Earth temperature around the canopy (°C) | 47.7 | 47.9 | 47.5 | 47.65 |
| Air temperature around the canopy (°C) | 41.42 | 41.39 | 41.35 | 41.31 |
| Percentage of canopy impact on the environment | 40.37% | 40.16% | 40.63% | 40.43% |

**Table 4. Results of climatic parameters of canopies simulated in ENVI-met, 12 o'clock at noon.**

| Canopy | Air temperature | Relative humidity | Wind speed |
|---|---|---|---|
| Reference environment (R) | 40.4 | 26 | 2.5 |
| Canopy 1×1 | 35.74 | 13.75 | 1.48 |
| Canopy 2×2 | 35.76 | 13.75 | 1.45 |
| Canopy 3×3 | 35.75 | 13.77 | 1.42 |

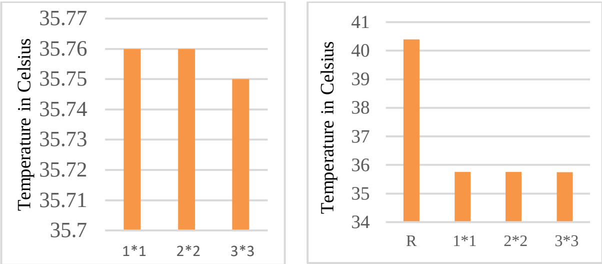



**Figure 4. Temperature comparison diagrams below the canopies simulated in ENVI-met.**

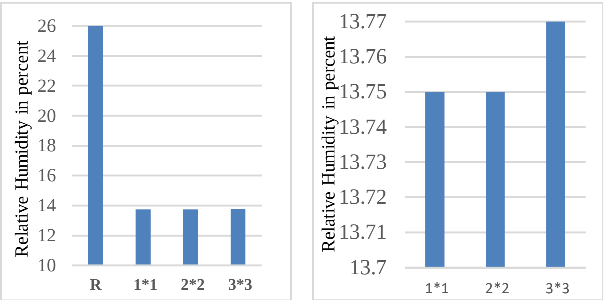



**Figure 5. Relative humidity comparison diagrams below the canopies simulated in ENVI-met.**

Based on the results of ENVI-met, the canopies in the environment can reduce the air temperature up to 5 degrees Celsius but by changing the canopy dimension, there is no noticeable change in the values of the climatic parameters. This can be due to the fact that the receptors are located exactly in the center of the canopy, while changing the canopy dimensions change the temperature to a larger extent but do not reduce the temperature much. The results of the receptors show that the presence of canopies in the environment is effective; however, as the canopy dimensions become larger, the effect of this dimensional change is not apparent at the center point below the canopy but the canopy impact level increases.

The canopy was simulated with dimensions of 4×4 square meters and a height of 2.70 m in ENVI-met with the location of Semnan and for the days of 3th of May (close to the comfort conditions), 7th of June (out of comfort) in 2020, and was compared with the results of 12th of August (one of the hottest days of summer and out of comfort). According to table 5, placing canopy in the environment causes positive changes in the climatic parameters compared to the reference environment (without canopy), which indicates the effect of the canopies on the environment. In the city of Semnan, in May, the conditions are almost comfortable, and this indicates the necessity of using canopies in the open spaces of Semnan from the middle of May. On 12$^{th}$ of August, placing a 4×4 square meters canopy in the environment will reduce the air temperature by 4.7 degrees Celsius.

## 8. Simulation in Ladybug

For the simulation in Ladybug, the location of Semnan was determined. The output of the simulations is for a few hot summer days at noon, and is 1.5 m above the ground. Table 6 is the dry inlet temperature for these few days in Semnan.
MRT of the simulation output for each canopy with a height of 2.70 m is shown in tables 7 and figures 6 and 7. By blocking the direct solar radiation, the outdoor shading is a crucial factor to decrease MRT [26]. According to these results, in the canopy with a height of 2.70 m, by increasing the canopy dimensions, the amount of MRT under the canopy decreases; this reduction continues to 3*3 dimensions; from the 3×3 dimension onwards, the decreasing process stops, and MRT under the canopy becomes a fixed value.

**Table 5. Results of climatic parameters of canopies simulated in ENVI-met, noon.**

| Day | Canopy | Air temperature | Relative humidity | Wind speed |
|---|---|---|---|---|
| 12th of August | Reference environment (R) | 40.4 | 26 | 2.5 |
| | Canopy 4×4 | 35.7 | 13.8 | 1.4 |
| 7th of June | Reference environment (R) | 32 | 32 | 3.3 |
| | Canopy 4×4 | 28.6 | 19.4 | 1.7 |
| 3rd of May | Reference environment (R) | 23.4 | 57 | 3.1 |
| | Canopy 4×4 | 20 | 33.1 | 1.7 |

**Table 6. Dry inlet temperature.**

| Time | 12 noon, 21st of June | 12 noon, 5th of July | 12 noon, 22nd of July | 12 noon, 5th of August |
|---|---|---|---|---|
| Dry temperature (C) | 36.6 | 33.9 | 40 | 31.6 |

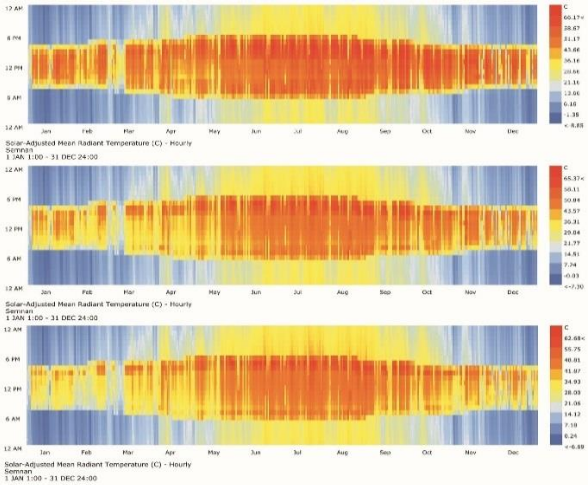


**Figure 6. Canopy MRT with a height of 2.70 m in degrees Celsius at a height of 1.5 m in the center of the canopies, noon; from top to bottom, 1×1, 2×2, and 3×3**

**Table 7. Canopy MRT with a height of 2.70 m in degrees Celsius at a height of 1.5 m in the center of the canopies, noon.**

| MRT | 1×1 | 2×2 | 3×3 | 4×4 |
|---|---|---|---|---|
| 12 noon, 21st of June | 46.32 | 42.10 | 40.46 | 40.46 |
| 12 noon, 5th of July | 46.87 | 43.53 | 42.24 | 42.24 |
| 12 noon, 22nd of July | 51.34 | 49.37 | 48.61 | 48.61 |
| 12 noon, 5th of August | 43.51 | 38.38 | 36.39 | 36.39 |

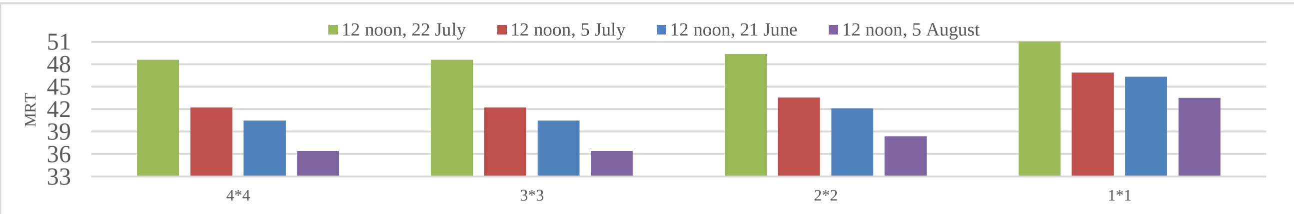



**Figure 7. Canopy MRT with a height of 2.70 m in degrees Celsius at a height of 1.5 m in the center of the canopies, noon.**

In table 8 and figures 8 and 9, MRT of the simulation output is shown for each canopy with a height of 3 m. According to these results, in the canopy with a height of 3 m, by increasing the canopy dimensions, the amount of MRT under the canopy decreases; this reduction continues to 5×5 dimensions; from the 5×5 dimension onwards, the decreasing process stops, and MRT under the canopy becomes a fixed value.

**Table 8. Canopy MRT with a height of 3 m in degrees Celsius at a height of 1.5 m in the center of the canopies, noon.**

| MRT | 1×1 | 2×2 | 3×3 | 4×4 | 5×5 | 6×6 | 7×7 |
|---|---|---|---|---|---|---|---|
| 12 noon, 21st of June | 49.38 | 45.15 | 43.28 | 40.46 | 40.23 | 40.23 | 40.23 |
| 12 noon, 5th of July | 45.75 | 42.42 | 40.94 | 38.71 | 38.53 | 38.53 | 38.53 |
| 12 noon, 22nd of July | 48.22 | 46.25 | 45.38 | 44.07 | 43.96 | 43.96 | 43.96 |
| 12 noon, 5th of August | 47.15 | 42.03 | 39.74 | 36.33 | 36.04 | 36.04 | 36.04 |

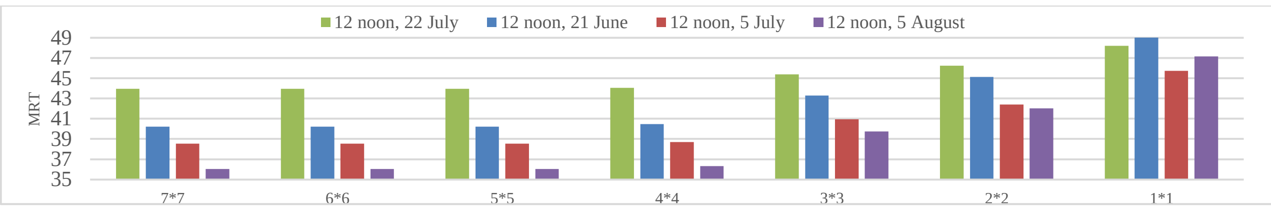



**Figure 8. Canopy MRT with a height of 3 m in degrees Celsius at a height of 1.5 m in the center of the canopies, noon.**

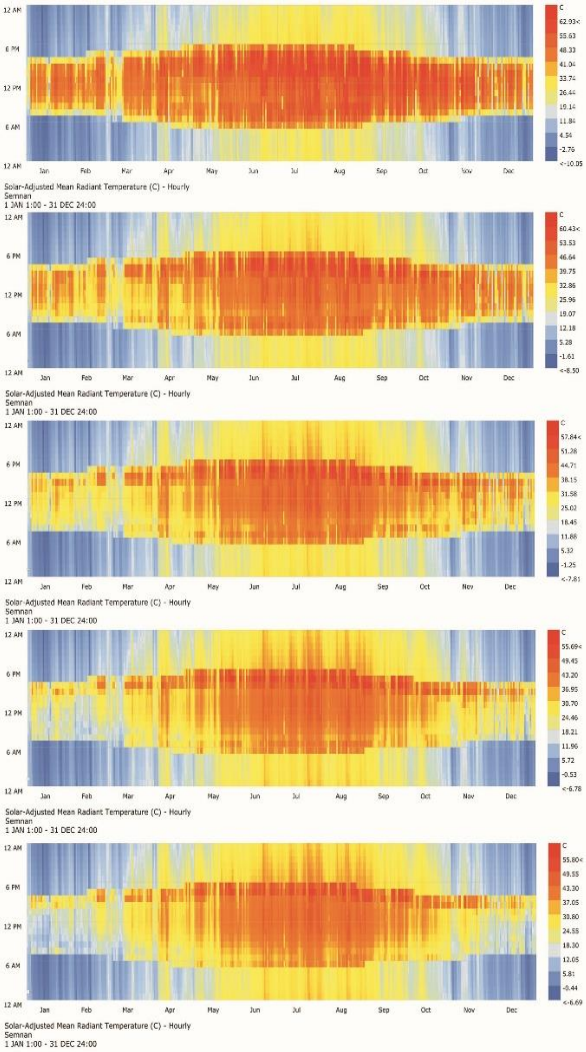


**Figure 9. Canopy MRT with a height of 3 m in degrees Celsius at a height of 1.5 m in the center of the canopies, noon. From top to bottom, 1×1, 2×2, 3×3, 4×4, and 5×5 canopies.**

## 9. Shade simulation in Revit software

The shade simulation was also performed in the Revit software in order to determine the appropriate dimensions of the canopy. Examination of the results showed that the larger dimensions of the canopy and the lower height of it cause a greater amount of shadow under the canopy, and the space under the canopy is shaded for more hours of the day. Also the distance from the center of the shadow to the center of the canopy is the same each hour for all canopies that have the same height. This distance also increases when the height of the canopies increases, which means that if the height of the canopy is higher, the distance of the shadow from the canopy increases. Therefore, it can be concluded that the larger dimensions of the canopy and the lower height of it cause a higher percentage of the shade under the canopy.

Table 9 shows some of the shadow characteristics of different canopies with a height of 3 m on June, 22$^{nd}$. As the dimensions of the canopy increase, the percentage of the shadow below it increases. The number of hours that there is shadow under the 5×5 and 6×6 canopies, is 9 h a day (8 to 16), and the number of hours that there is shadow under the 7×7 to 11×11 canopies, is 11 h a day (from 7 to 17). It is also observed that from 5×5 onwards, increasing the canopy dimension has little effect on increasing the percentage of the shade under the canopy. In comparison of the 6×6 canopy shade to 5×5, the shade increases only 2%; therefore, it can be concluded that the canopy with dimensions of 5×5 is suitable, and has a good performance in the environment.

**Table 9. Comparison of shadows of different canopies with a height of 3 m on June 1, noon.**

| Dimensions | 1×1 | 2×2 | 3×3 | 4×4 | 5×5 | 6×6 | 7×7 | 8×8 | 9×9 | 10×10 | 11×11 | 12×12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area ($m^2$) | 1 | 4 | 9 | 16 | 25 | 36 | 49 | 64 | 81 | 100 | 121 | 144 |
| Maximum percentage of shadow area under canopy than canopy area | 35% | 67% | 78% | 83% | 87% | 89% | 90% | 92% | 93% | 93% | 94% | 94% |
| Number of hours of shadow under canopy | 3 | 5 | 7 | 8 | 9 | 9 | 11 | 11 | 11 | 11 | 11 | 12 |
| Hours | 11-13 | 10-14 | 9-15 | 8-15 | 8-16 | 8-16 | 7-17 | 7-17 | 7-17 | 7-17 | 7-17 | 6-17 |

## 10. Conclusion and Results

Shade is one of the most important factors involved in providing the thermal comfort. It controls the sunlight, and reduces the discomfort caused by a short-wavelength radiation. Besides, the shadow on the ground reduces the surface temperature and increases the radiation of waves with long wavelengths. The lack of shade in urban environments raises the temperatures of air and surfaces. Shading with vegetation and artificial elements is one of the main ways to reduce the heat stress in hot summer hours. Shading by natural elements (trees) has its limitations; for example, it takes a long time for the trees to grow and reach the shading stage, while shading is provided by artificial elements (membrane canopy) quickly and easily. Due to their lightness, flexibility, a high reflection of sunlight, utilization of stack effect, and special thermal properties, the membrane canopies cause an effective shading in the environment and reduce the temperature. Therefore, they are very suitable for use in open spaces, especially in warm climates such as Semnan.

The results of the field studies including data collection in several models of membrane canopies in open spaces in Semnan showed that the lightweight membrane canopy reduced the temperature up to 7.8 $^{o}$C, and had a positive effect on the environment. By simulation in the Ansys software among four canopies, the saddle model was identified as a suitable canopy model. Simulation in the ENVI-met software showed that the presence of canopies in the environment had a positive effect on improving the climatic parameters. Simulation in Grasshopper and Ladybug Plugin identified dimensions of 5×5 square meters with a height of 3 m as suitable dimensions of the canopy and the shadow simulation in the Revit software also confirmed the simulation results in Ladybug, and identified the dimensions of 5×5 square meters with a height of 3 m as suitable dimensions of the canopy. Therefore, a saddle canopy with dimensions of 5×5 square meters can be introduced as a suitable canopy for the hot and dry climate of Semnan. This canopy is portable and flexible, and it is suitable for a neighborhood park in the hot and dry climate of Semnan, and it can be arranged according to the dimensions and shape of the space in the parks.

## 11. Post scripts

**MRT:** Mean Radiant Temperature; MRT is a very important parameter as it affects both the thermal comfort outdoors and the energy flux crossing the buildings and walls, and hence, the thermal comfort indoors. MRT is defined as the uniform temperature of an imaginary enclosure (or environment), in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure (or environment) [27].

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