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EVALUATING THE OPTIMIZATION OF IMPACT OF SHADING IN TEHRAN URBAN SPACE BASED ON COMPARISON TECHNIQUES: THE CASE STUDY IN BRT STATION

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ABSTRACT

Improving the quality of open spaces and human comfort is necessary for more human-inaccessible spaces. Therefore, bus stations as open spaces for traveling thousands of people continuously are considered essential in absorbing sun rays and providing comfort. This paper investigates the performance of BRT stations in Tehran province in the summer, considering the highest shading. The second stage proposes a new graphic cable-stayed roof to compare the sun's path and shade. Ten stations of Moein-Tajrish terminals with South-North orientation were selected in this regard. Then, all the station details were calculated and analyzed in the Grasshopper Modeling Software. And the shadow and sunlight were evaluated and analyzed during the summer months between 12 am to 2 pm at noon. In order to evaluate the compatibility of the selected samples, three variables, including orientation, the height of the awning, and the slope of the awning, were considered orientation of 5, the height of 1, and the gradient of 19 introduced as the most optimal model. Also, studies and analyses were carried out in Honey Bee & Ladybug plugins, including Qualitative Analysis, Hourly Quantitative Analysis, and Energy Quantitative Analysis. The results showed that the selected case sample is more than 55% in the desired shading. The second stage proposes a new graphic cable-stayed roof to compare the sun's path and shade for the structure.

Keywords: External shading, evolutionary parametric optimization, energy demand, urban space, temporary systems.

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1. INTRODUCTION

Thermal comfort is one of the aspects of urban livability that has attracted the attention of researchers in recent years because it can impact urban factors such as city architecture and urban open space [1]. The thermal comfort of open city areas is one of the most critical factors in people's social life, urban economic relationships, and controlling people's health against harmful solar rays like reducing the risk of skin cancer [2]. Designing an awning with more light levels, optimized use of the configuration, and lower cost for materials and construction is considered a fundamental challenge in open space design. Another matter concerning solar energy is its high levels in the summer month and the change of the angle and rate of reflection in the winter, spring, and autumn seasons. Several factors affect urban space, such as solar radiation, climate, shading, environment, and temperature, showing each design stage examination [3]. In order to provide thermal comfort, various parameters, such as the system's orientation, the environment, and the type of use of the structure, are fundamental [4, 5].

Traditionally, many measures were taken to design the awning, such as decorating metal columns and hanging spears, balls, or other embellishments awnings were rolled up against the facade of the building when it did not rain. Maintenance in winter is different, as the awning should be stored in a warehouse instead of attached to the support. It has been used for centuries to make tents and sails with cotton canvas as the fabric for the awnings. There was widespread use of awnings following the civil war. Since the establishment of industrial enterprises (industrialization) in the middle of the nineteenth century, iron plumbing has been adapted for awning frames. It was available and affordable to make awnings, and they could be easily formed and attached to create a wide array of shapes and sizes. Canvas mills and sailmakers had to find new markets due to the advent of the steamship. It was possible to create fabrics that could be used in storefronts due to the development of the awning industry [6].

Considerable architects have studied in the field of different microclimate characteristics, including thermal comfort, which can have a significant impact on the design of elements in the urban space; some of these include: The result of the study on improving the thermal comfort of outdoor systems for satisfying uses in Hong Kong people showed that solar radiation intensity, wind speed, and air temperature are significant factors in specifying the thermal feeling of people outdoors [7]. The experimenters [8] conducted their study to understand better the psychological aspect of people using outdoor spaces and its effect on parameters in designing public spaces. In this study, the thermal environment is one of the most critical points in people's use of these spaces. Among other methods for a better understanding of the thermal environment on individual behavior and its implication can mention simultaneous dimensions of thermal comfort variables [9] and air temperature, air humidity, wind rate, and international radiation [10].

One of the factors required in this discussion, which is efficacious in thermal comfort in the long-term, is the shading system because it can block the sun's path and create a suitable space [11]. There have been numerous studies on the role of shadows on

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thermal comfort in various climates, such as cold and temperate as well as tropical, some of which are listed below. Taotao Deng and John D. Nelson focused on empirical Bus Rapid Transit (BRT) analysis. They demonstrated it is a cheap, high-speed, and efficient transportation system for the urban city [12]. Dušan Katunský et al. studied and optimized the shading system based on solar energy in a specific period and different seasons of years and showed results in two-stage, the optimal shape of the system and optimizing the dimensions of the system's configuration. Also, this research demonstrated that the design of elements of the shading systems is only for a specific time and should have the maximum amount of shadow by different sun angles [13]. Based on [14], the authors assessed the effects of seasonal changes on outdoor comfort in subtropical climates and the shading of urban streets. Some shading systems can be added to urban streets in summer, and in winter, they are eliminated. The results suggest that a particular shade level is best for urban roads. The correlation analysis revealed that in the spring, summer, and autumn, thermal comfort is enhanced by shaded locations; in the winter, it is improved by bare sites. Various tools have been used for designing and checking for shading [15].

Grasshopper illustrates the famous parametric software program, which is executed with the help of the Rhino software [16,17]. Furthermore, it has many environmental open-source plugins, such as Ladybug [18]. Ladybug is an interface that unites some simulation engines, for instance, Energy Plus [19] and Radiance [20], to explore a more comprehensive range. Researchers in this study [21], the availability of solar energy in an urban environment has been investigated by using the parametric tools of Grasshopper and other complex plugins, which after examining the urban fabric with tall and short buildings and the amount of shading, show that Buildings with a higher peak and open space will be more efficient for the winter season. The research [22] considered three different climates when designing a bus stop shade. Providing comfort to occupants was the key to minimizing shade material. Three steps are involved in the comfort cover method. As a first step, the technique measured the radiation falling on a person to calculate the solar-adjusted radiant temperature and to analyze the Universal Thermal Climate Index (UTCI) used to identify thermal stress ranges. This study showed that this method is appropriate for most design applications and is suitable for the visual programming of Grasshopper through Ladybug tools.

2. RESEARCH METHOD

The general goals of this project include providing the highest amount of shading in desired seasons and preventing excessive summer heat according to the pre-determined requirements. A descriptive-analytical method has been used in this paper. First, ten stations (Tajrish-Moein) out of the 34 BRT stations located in the North-South of Tehran were selected to determine the shading of BRT stations. The pattern of choosing the stations is in the manner that the direction of the BRT was divided into three parts, including initial, middle, and final routes & the initial route has been selected considering the need for more diversion of the route & North-South direction. In the next step, in the Rhino software and

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with the grasshopper plugin, the station was simulated according to the field measurement with a length of 43 m, width 1 of 2 m, and height of 3.5 m. The Galapagos, Honeybee, and Lady Bug plugins have been utilized to optimize the shading of stations. There are variables for explaining this matter, including height, gradient, and station orientation.

Among the influential parameters in the shading (Table 1), the height, orientation, and roof inclination are selected according to the site constraints and distinctive parameters compared to the rest. Subsequently, by determining the range of three months in summer from 12 am to 2 pm, because the difference between the sun's angle in the north-south orientation of a city does not vary, and the distance between stations is short; therefore, we began to analyze a specific station.

Tehran province, with the centrality of Tehran city, with an area of around 12.981 square kilometers, is at latitude 43-43.5 degrees North and longitude 54 -55 degrees east. The province is limited to Mazandaran province in the North, Tom province in the south, the central province in the southwest, or province in the West, to Semnan province in the East.

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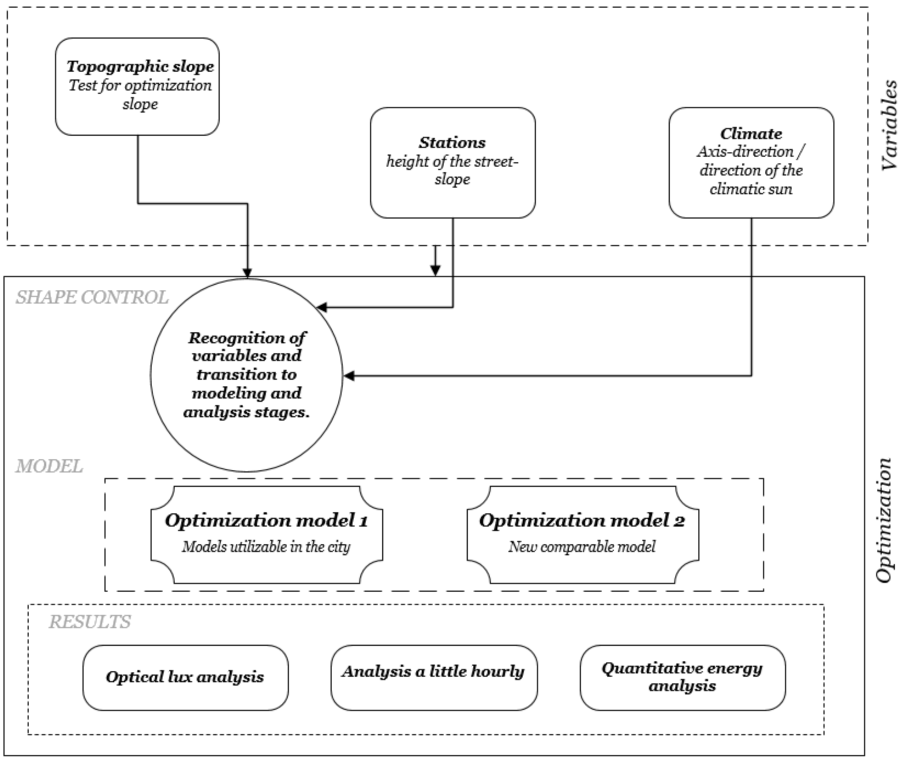

Figure 1**.** Workflow in the computational model and analysis

3. BUS RAPID TRANSIT (BRT) IN TEHRAN

Transportation is significant in a city's mobility, especially in a metropolis. BRT is considered one of the massive transportation ways that have haven used with high speed, more security & safety, flexibility, and lower cost, compared to the older transportation systems. The use of BRT as one of the economical and effective rail transportation ways has been adopted among other transportation methods. Since 2005, more than 270 BRT systems have been created worldwide.

BRT system has emerged as one of the ways of transporting urban passengers in recent decades of the twentieth century, which can carry and transport a wide range of passengers. The BRT system has also been developed throughout Latin America, North America, Northeast Asia, China, Australia, Africa, India, and Iran. The concept of BRT has been adopted for the first time in the North American region, and the use of this word in other parts of the world is increasing. The same concept is used in different places [23].

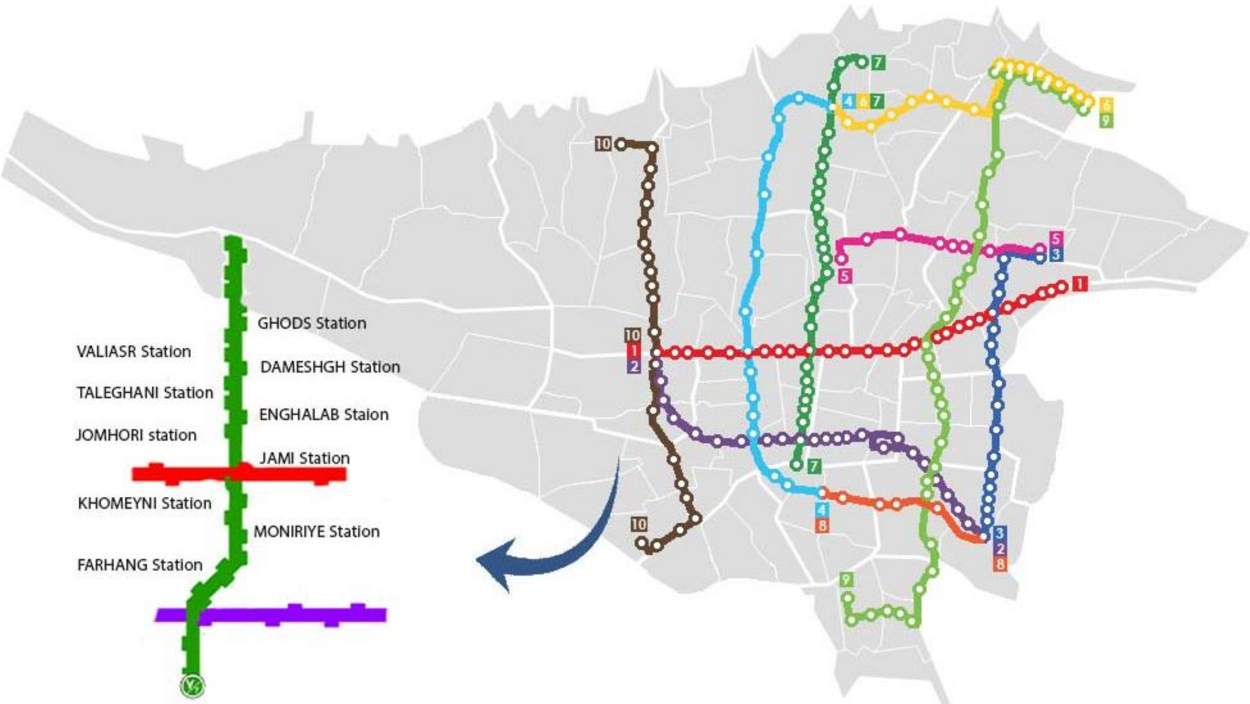

Figure 2. BRT routes in Tehran city and selection stations [23]

4. MODELING AND SIMULATION OF STATION

Parametric modeling of the station in Grasshopper Software [20] was the first step for the analysis. In the next step, using the Galapagos plugin [21], the largest shading area has been optimized by changing the station's height, inclination, and orientation. According to the optimization, among the 35 obtained results, 15 final results that show the highest amount of shading have been recorded (see Table 1).

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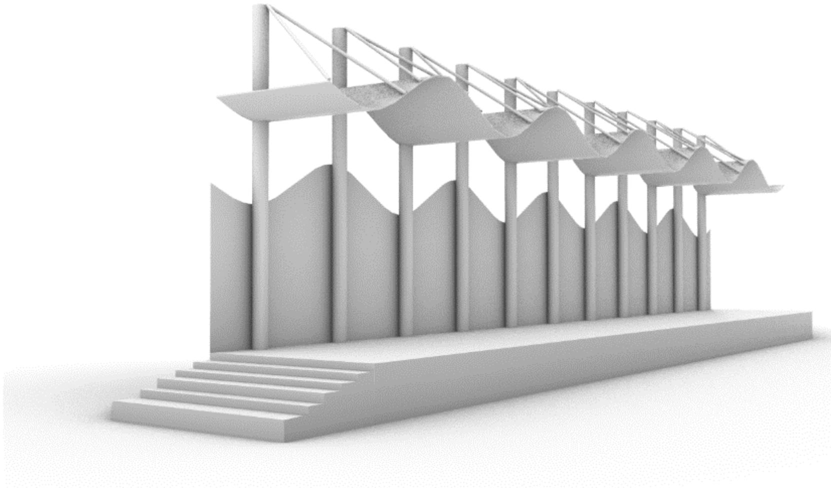

Figure 3. Parametric modeling of the station

Table 1: Recorded 15 final results, available parametric model

Stage	Orientation [-5◦, 5◦]	Height [0 *m*, 1 *m*]	Roof inclination [-23◦, 0◦]	Shading
1	5	0	-19	**142.129437**
2	3	1	-20	**139.428208**
3	4	0.73	-19	**139.259535**
4	5	0.70	-18	**136.746675**
5	2	0.72	-20	**136.389135**
6	3	0.80	-23	**136.015806**
7	4	0.70	-21	**135.915407**
8	0	0.90	-18	**135.679269**
9	1	0.70	-21	**135.622932**
10	1	0.90	-20	**135.098046**
11	-1	1	-18	**135.054266**
12	-1	1	-15	**135.056495**
13	-1	1	-14	**134.456987**
14	3	0.70	-23	**134.364591**
15	4	0.60	-22	**134.982621**

5. RESULT FROM ANALYSIS AND DISCUSSION

This research utilizes four types of analysis; finally, the results are compared. In this phase, Ladybug is used to function targeted studies of local weather facts via importing the EPW file of Cancun and to run sunlight-trajectories modeling. To seize the site-specific and dynamic interplay of the shadings, consultant days and hours had been chosen for the quantification of UTCI values and shaded areas: 21 Jun (winter solstice) 21 July, 21 Agust, During 186 hours of Sun radiation, 12:00 until 2:00 time

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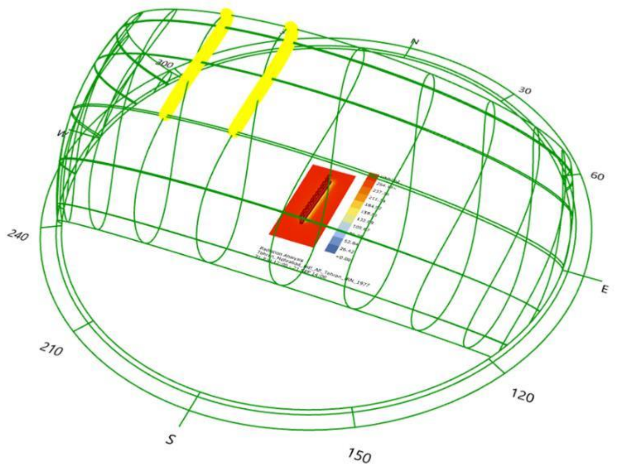

Figure 4. Shadings positions and periods according to the sun

5.1. Optical lux analysis

This analysis is a qualitative analysis that is calculated using the Honeybee plugin in the Grasshopper software. During 186 hours of Sun radiation, the red spots received 100% of LUX light above 2000, and the blue spots (station footprint) received 0% of light. A series of yellow spots have received 58% of LUX light between 100 and 2000 during 90 hours out of 186 hours.

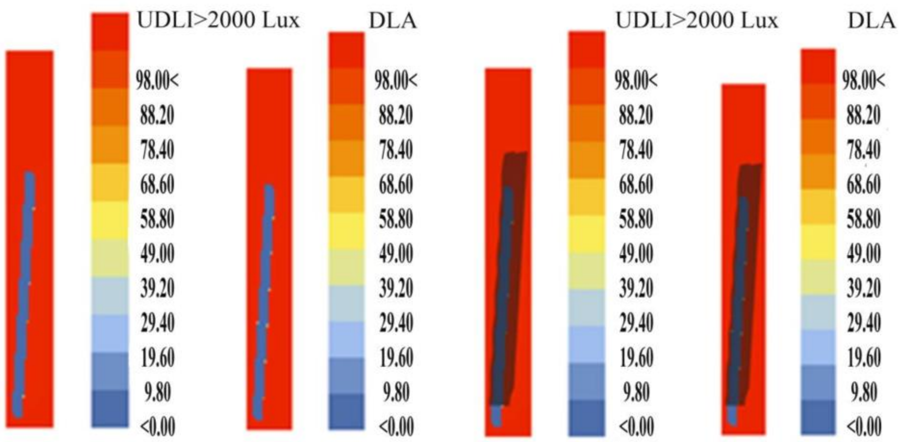

Figure 5. Analysis graph of daylight in terms of lux unit

5.2. Hourly quantitative analysis

The temporal analysis, based on the solar diagram in Tehran, obtained from the temporal analysis, has been calculated with the Ladybug plugin in the Grasshopper software, indicating the sum of hours that the station has received daylight in the specified period.

According to the chart, the following spots are exposed to severe sunlight as follows:

The yellow, red, and blue (footprint station) spots show the luxing for 186 hours, 93 hours, and 0 hours, respectively. Using the data obtained, the station model has been placed in the shadow for 55% out of 100% of full sunlight radiation during the considered 186 hours (three months in summer between 12 –2 pm) (see Fig. 6).

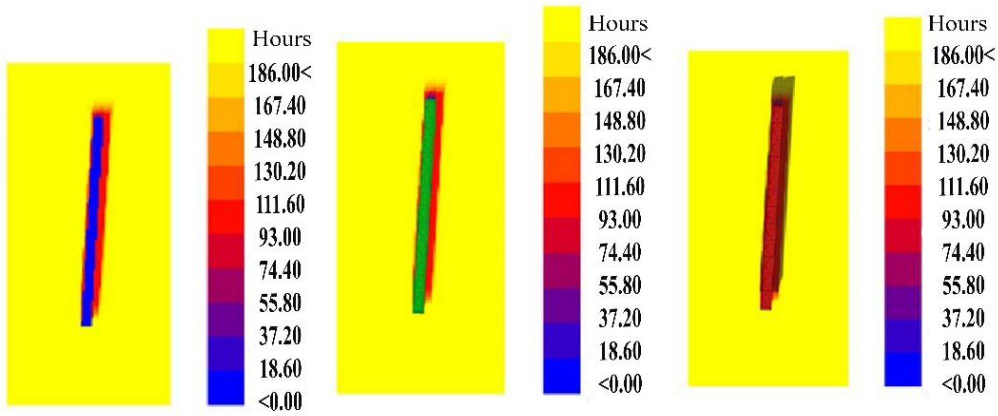

Figure 6. Analysis graph of hourly quantitative

5.3. Energy quantitative analysis

According to an Energy, Analysis carried out using the Lady Bug plugin, the maximum of the Sun Energy (red spots) in 3 months of the summer is 264.18 between 12 –2 pm, and due to awning, the yellow spots have received the energy of 184-92 to 185-51 & the blue spots (footprint) has received no energy. 55% of the time, solar energy has been received, and the rest of the hours have been placed in the shadow (see Figure 7).

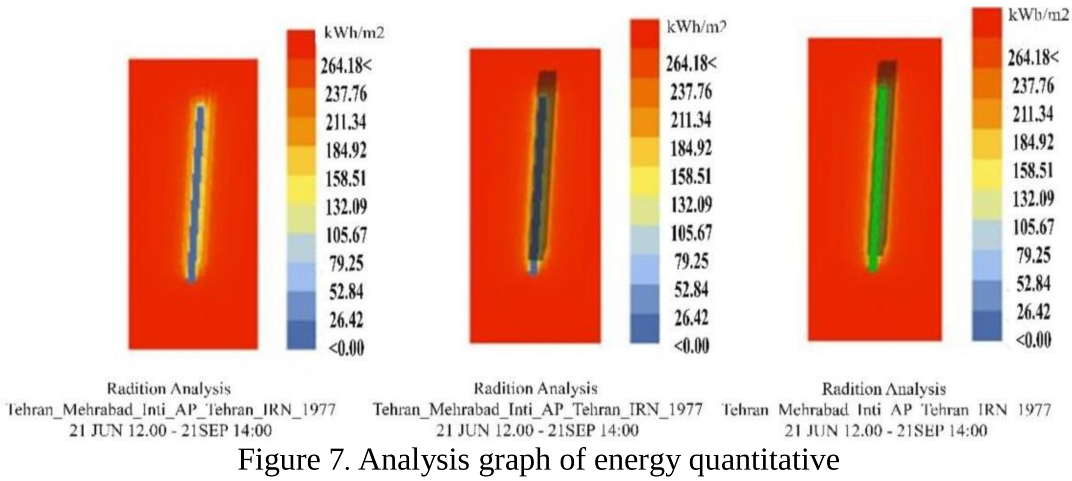

Figure 7. Analysis graph of energy quantitative

5.4. Parametric system design

At this stage, it considered the initial variables, including the structure's height, the earth's topology, and the sun's angle at a specific time. A new parametric system was designed from a cable-dependent roof with three strong cantilevers (see Figure 8).

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The height of the roof in the middle is more than the corners, which causes a slope of 22 degrees in the proposed system. According to the optimization, like the main model of 35 results, 15 final results are recorded, which show the highest amount of shadow according to the main variable in Figure 5. The designed model has features compared to the existing model that has increased the amount of shading to about 13%. The designed parametric model covers a higher height and reduces the material's use by 21%.

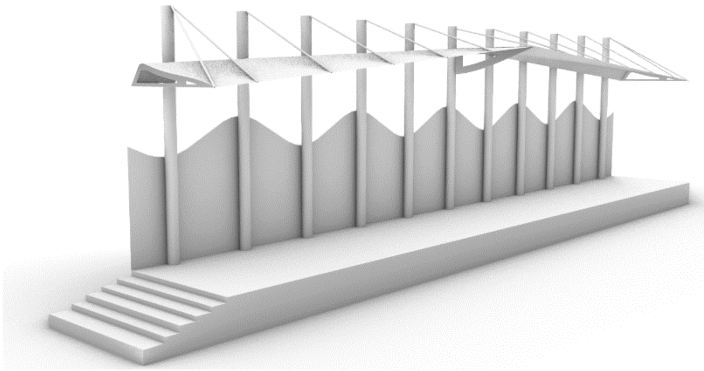

Figure 8**.** BRT routes in Tehran city and selection stations

Due to the high traffic in the stations and the use of fossil fuels, the existing model cannot prevent the accumulation of pollutants due to the wave created on the roof. Therefore, the designed parametric system dramatically reduces the number of contaminants due to the lack of curvature and the absence of corners (see Table 2).

Table 2: Recorded 15 final results, new parametric model

Stage	**Orientation [-5◦, 5◦]**	**Height [0 *m*, 1 *m*]**	**Roof inclination [-23◦, 0◦]**	**Shading**
1	4	0.83	-11	**159.269875**
2	5	0.98	-16	**156.346214**
3	4	0.84	-15	**153.953483**
4	2	0.65	-20	**141.696458**
5	1	0.76	-21	**139.953251**
6	-3	0.83	-14	**139.833136**
7	5	0.89	-19	**138.733264**
8	1	1	-23	**138.632533**
9	3	1	-14	**136.987631**
10	-5	0.63	-22	**136.626566**
11	4	0.94	-23	**136.325523**
12	-3	0.85	-17	**135.923654**
13	-5	1	-19	**135.653564**
14	5	1	-21	**135.323251**
15	-3	0.84	-18	**134.323262**

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6. CONCLUSION

The bus stop is considered a public & crowded space in all cities worldwide. Thousands of people in towns wait for bus stops to arrive at their destinations every day. In order to investigate the most optimal shading position in bus stops in the hot weather in the summer season, in the period of 12 to 2 pm in the maximum sunlight radiation, ten bus stops were selected in North-South orientation. In the next step, shading & sunlight radiation spots were analyzed & calculated using Grasshopper software & Galapagos, Honey Bee & Lady Bug Plugins.

By analyzing the LUX optical diagram, an hourly quantitative diagram, and a quantitative energy diagram, the following results were achieved respectively:

(1) Yellow spots received 58% of the lux light between 100 and 2000 during 90 hours out of 186 hours.

(2) Red spots received 93 hours out of 186 hours & Blue spots (station footprint) received 0 hours out of 186 hours.

(3) Yellow spots have received energy of 184.92 -185.51 & the footprint (blue spots) has received no energy, indicating that solar energy has been received for more than 50% of the period & the rest of this time, the station was exposed to the shadow.

(4) In the last stage of this research, a comparison was made between the existing and the designed parametric models, based on which a 13% improvement in shading was created.

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