# Evaluating Outdoor Thermal Comfort in Two Neighborhoods in Sulaimani City

**By:**
**Mohammed Jalal Mohammed**

## Abstract
Outdoor thermal comfort is an important consideration in any urban planning process. To achieve outdoor thermal comfort in neighborhoods, applying design measures and sustainable strategies in the design and construction process is crucial. Achieving outdoor comfort spaces is critical to mitigating climate change's impact, enhancing its citizens' quality of life, and inviting people to stay there. The main problem is the lack of climatic consideration in urban planning and design. This research aims to evaluate the effect of design measures on outdoor thermal comfort in two residential neighborhoods in Sulaimani city. It used a quantitative method by using the ENVI-met software based on simulating air temperature and mean radiant temperature on the hottest day in the summer of ٢٠٢٣. The results reveal that the two neighborhoods have not provided a comfortable space during the summer, but they showed that the first neighborhood is better due to the performance of design measures in it. The findings detect some conclusions to enhance outdoor thermal comfort to be the basis for improving now and achieving future planning in residential neighborhoods.

**Keywords:** Outdoor thermal comfort, Design measures, Sustainable strategies.

## ١. Introduction

More than half of the population of the world resides in urban areas .by the year ٢٠٥٠ is projected to increase to about ٧٠٪ [١]. The population of the world has only increased six times in the last ٢٠٠ years, but the population of cities has increased ١٢٨ times [٢]. With the growth in population, cities have also grown in size. The shift of the human population towards urban centers caused the loss of agricultural lands [٣].It also caused an increase in human activity such as an increase in buildings, the transformation of the natural landscape, the reduction of vegetation cover, and an increase in surfaces such as concrete and asphalt [٤]. All of them, lead to thermal discomfort in cities because of increased temperature, reduced ventilation, and rising environmental challenges that threaten urban areas [٥]. Outdoor Thermal Comfort is a crucial factor that must be taken into account because it can positively affect people's social and economic behavior until a sustainable built environment is achieved that ensures the residents' psychological and physical well-being [٦]. Additionally, thermally comfortable outdoor environments will benefit indoor environments as well, which will result in less energy being used for space conditioning [٧]. Improving and achieving outdoor thermal comfort is a critical factor in establishing urban life and functionality. The thermal comfort of the people is directly associated with urban design [٨]. By understanding design measures and the effect of sustainable strategies on urban planning, the urban area can be planned and arranged more sustainably and comfortably therefore, to build an outdoor thermal comfort space, planners and designers must consider design measures and strategies for enhancing outdoor thermal comfort [٩].

## ٢. The Concept of Outdoor Thermal Comfort

Satisfaction with the thermal environment is known as outdoor thermal comfort. This state of mind can vary from person to person, even among people living in the same location, depending on the person [١٠]. When the rate of heat produced by metabolism and the rate of heat lost by the body is in equilibrium, it has been achieved [١١]. Indeed, thermal comfort in outdoor spaces is necessary for three main reasons: firstly, creating of climatically comfortable space for the users. Secondly, minimizing the consumption of energy use. Finally, the creation of standards to increase thermal comfort [١٢]. It is difficult to quantify since it is dependent on a wide variety of parameters that impact pedestrians and cannot be defined by a single parameter [١٣]. There are two classes of parameters used to assess outdoor thermal comfort personal parameters and environmental parameters. Connections between these parameters in the estimation of different heat gains and losses around the human body [١٤]. Figure ١ shows the parameters of outdoor thermal comfort. These parameters determine the quality of open spaces, to which pedestrians are directly exposed.

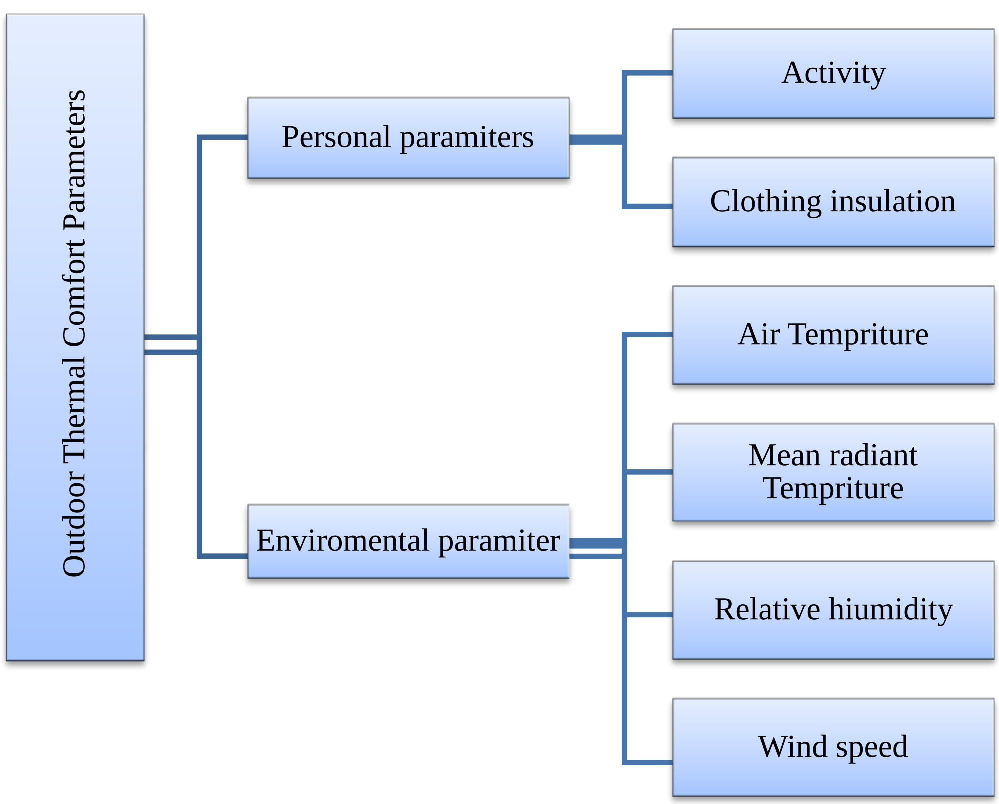


**Figure ١: Outdoor thermal comfort parameters (by researchers)**

## ٣. Methodology

The consequences of design have a significant impact on the urban microclimate such as landform, urban pattern, street design, building height, average vegetation, and surface materials. All of them shift outdoor spaces by influencing outdoor parameters. They are classified into three categories, including macro level, intermediate level, and micro levels, as shown in Figure ٢. The study to achieve its objectives two neighborhoods were chosen there are Nawroz and Nali cities which are located in Sulaimani city, as shown in Figure ٣. The two neighborhoods were analyzed and compared based on the design measures, as shown in Table ١. The Envi- met simulation tool was used for comparison [١٥]. Sulaimani city is located in the north of Iraq. It has a semi-arid climate with very hot dry summers and cool wet winters with large temperature differences between day and night and between summer and winter. According to received data from the director of metrology Sulaimani.the hottest months fall in July and the coldest months are in January in ٢٠٢٣, the hottest day is on the ٢٧th of Jul, and the coldest day is the ٢٣rd Jan. This research is done in the summer because heat stress is most common in outdoor spaces in the summer. To assess the whole two neighborhoods' thermal performance, simulations were held on the hottest day the ٢٧th of July as a representation of the summer period. The study received ١٢ noon on this day because taking more hours causes a lot of similarities and complexity, which isn't good for research. Therefore, for simulation, the weather data hottest day (٢٧th Jul ٢٠٢٣) in Sulaimani is needed.

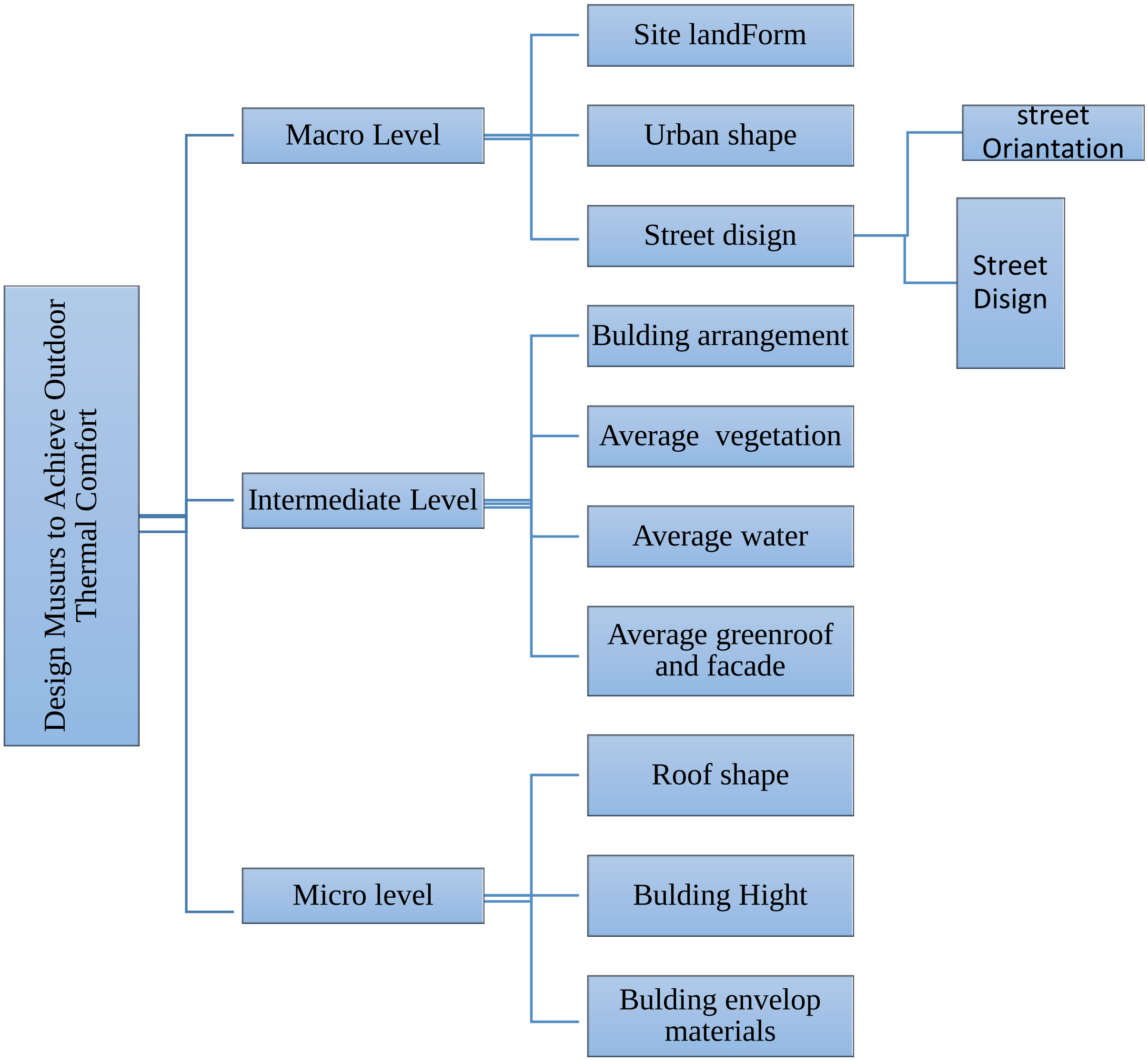


**Figure۲: Design measure for achieve outdoor thermal comfort (by researchers)**

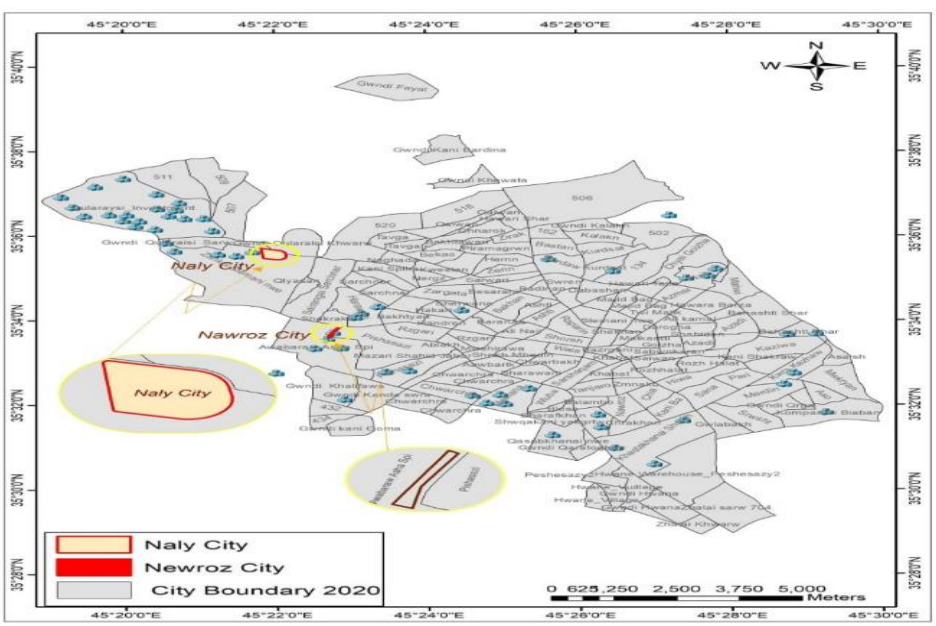


**Figure ۳: The location Nawroz and Nali cities in Sulaimani**

| NO. | Measures | Nawroz city | Nali city |
|---|---|---|---|
| ١ | Site land form | Flat<br> | Flat<br> |
| ٢ | Urban shape | Linear and Dispersed<br> | Linear and Dispersed<br> |
| ٣ | Street wind orientation | Not stable | Not stable |

| | | | |
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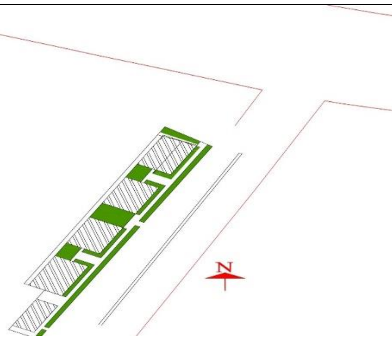
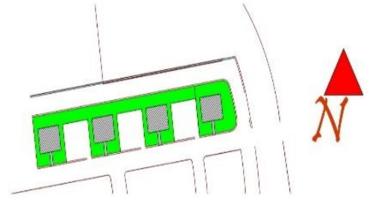
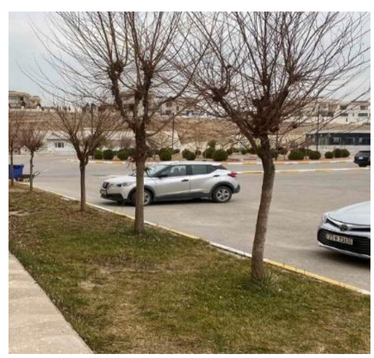
| | |  |  |
| ٤ | Street canyon geometry | Deep canyon  | Shallow canyon  |
| ٥ | Average vegetation | ٪٢٠  | ٪١٥  |

| | | | |
|---|---|---|---|
| ٦ | Pavement material | High albedo<br> | Low albedo<br> |
| ٧ | Building height | two times more than the street width<br> | Three times less than the street width<br> |
| ٨ | Building envelop material | High albedo<br> | High albedo<br> |

**Table ١: Comparison between Nawroz and Nali cities according to design variables (by researcher)**

## ٤. Simulation Process

The simulation has been implemented by Envi-met software. In the first step, the model domain was modeled through the geographic coordinate of Sulaimani Latitude: ٤٥,٤٣N, Longitude: ٣٥,٥٦ E. In the second step, the model was created by inputting information about the area location, as shown in Figure ٤. This includes building shapes, materials, vegetation, and open spaces, see data in Table ٣. In the third step, the model needs input parameters, which are used to determine all necessary meteorological components received from the director of metrology Sulaimani as shown in Table ٣.

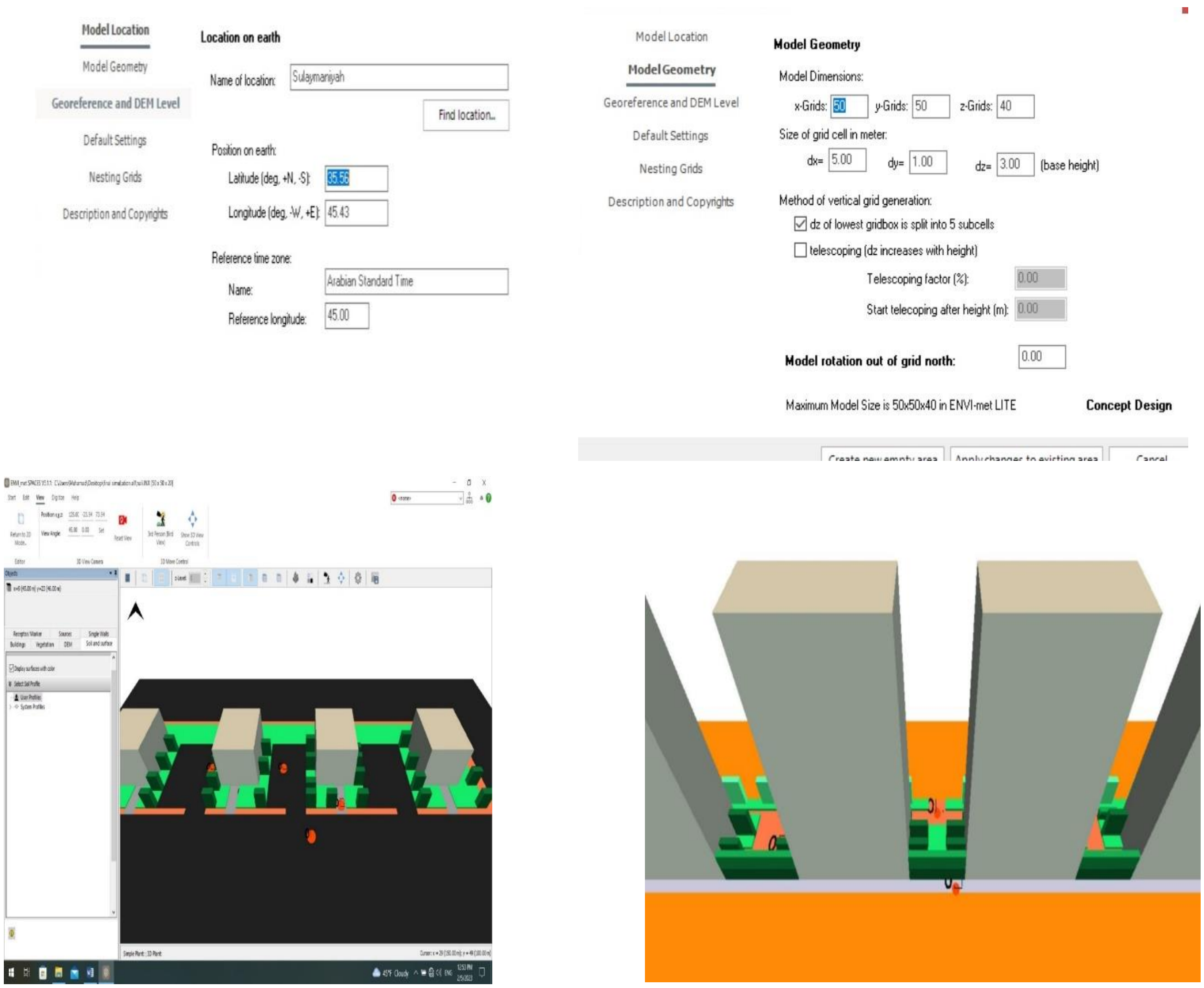



**Figure ٤: ENVI-met and model area inputs**

| Model Area | Nawroz city | Nali city |
|---|---|---|
| Area | ٨٠٥٥m٢ | ١٥٠٠٠m٢ |
| Number of buildings | ٥ | ٤ |
| Area of buildings | ٣٦١٥m٢ | ١٦٢٠m٢ |

| | | |
|---|---|---|
| vegetation | ١٥٤١m٢ | ٢٥٠٠m٢ |
| Street and corridor | ١٩٩٠m٢ | ٩١٠٠m٢ |
| hardscape | ٨٠m٢ | ٥٠m٢ |

**Table ٢: Model area inputs**

| | |
|---|---|
| Day | ٢٧th jul ٢٠٢١ |
| Start time | ٧am |
| Simulation time | ٢٤ hour |
| Time of maximum air temperature | ١٢pm |
| Maximum air temperature | ٤٦ |
| Time of minimum air temperature | ٣am |
| Minimum air temperature | ٢٨ |
| Time of minimum real humidity | ١٢pm |
| Minimum real humidity | ١٥ |
| Time of maximum real humidity | ٣am |
| Maximum real humidity | ٤٣ |
| Average wind speed | ٢m/s |
| Average wind direction | ٣٥٠ |
| Specific humidity | ٩,٢ g/kg |

**Table ٣: Meteorological data entry**

## ٥. Results and Discussion:

### ٥,١ Air Temperature

The air temperature was analyzed for Nawroz and Nali cities at ١٢ pm as shown in Figure٥ and ٦.

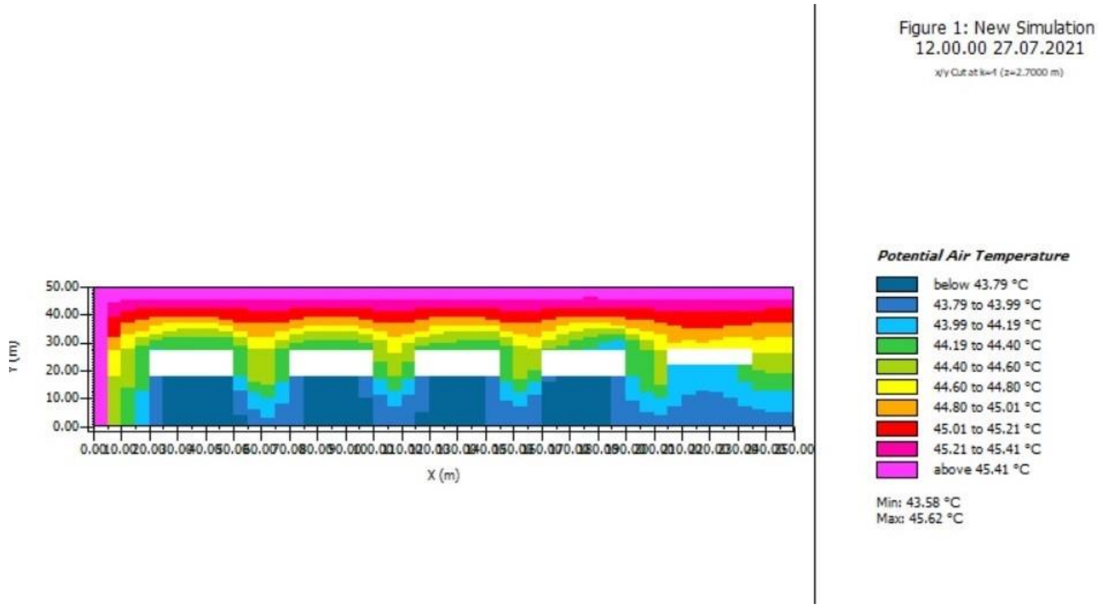



**Figure٥: Air temperature on ٢٧th of July at ١٢:٠٠ pm in Nawroz city**

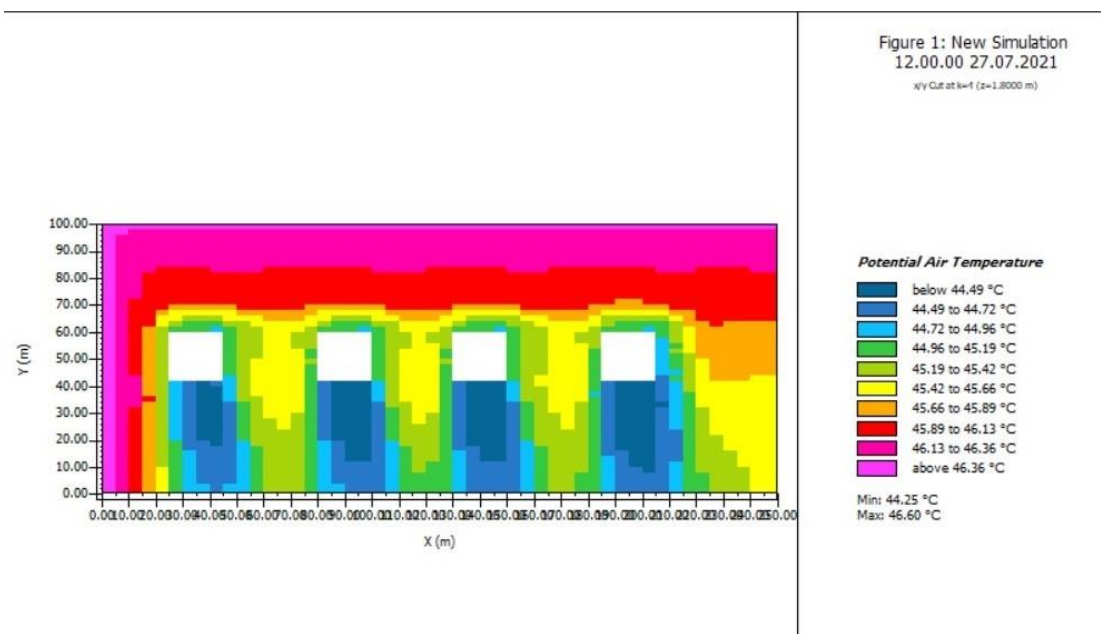



**Figure٦: Air temperature on ٢٧th of July at ١٢:٠٠ pm in Nali city**

The results of the simulation reveal that the temperature of Nawroz city is between (٤٣,٥٨- ٤٥,٦٢) °C, and the average temperature is (٤٤,٦) °C. ٪٧٥ of the study area from minimum to average, and ٪٢٥ of the study area from average to the maximum. The results of the simulation revealed that the temperature in Nali city is between (٤٤,٢٥-٤٦,٦) °C, and the average temperature is (٤٥,٤٢٥) °C. % ٤٥ of the study area from minimum until to average, ٪٥٥ of the study area from average to maximum see Figure ٧. According to ASHRAE standards, the average temperature in the two neighborhoods is more than the highest range.

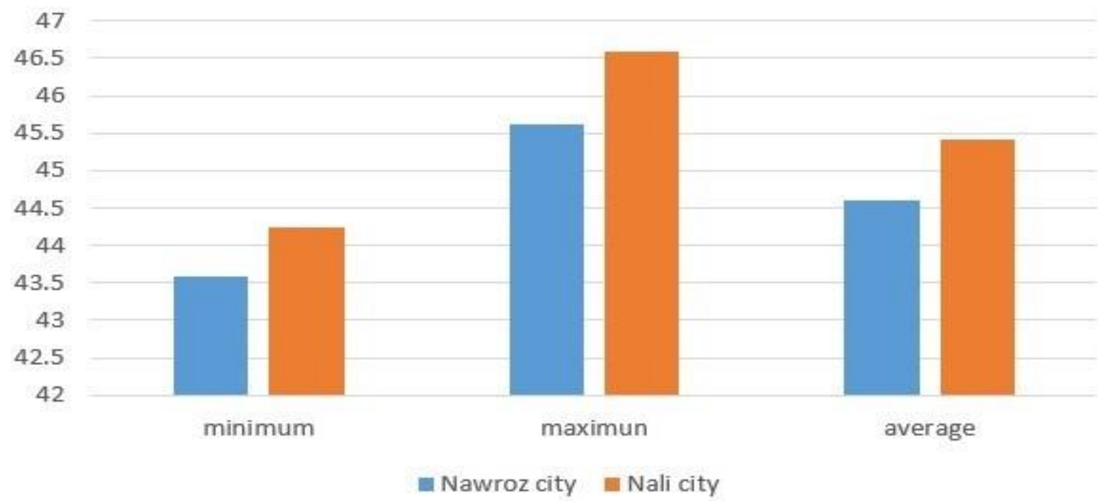



**Figure ٧: Range air temperature on ٢٧th of July at ١٢:٠٠ pm in Nawroz city and Nali city**

According to simulation results showed in both Nawroz and Nali cities, the temperature is generally cooler around buildings and in places with vegetation and shade in the study area. Buildings' height, orientation, street canyons, albedo materials, and plantation have a considerable impact on outdoor thermal comfort .But Nali city is hotter than Nawroz city for these reasons:

١- The height of buildings and the high rate of aspect ratio creates more shade in Nawroz city, which reduces the amount of sunlight exposure, especially for the area around buildings.

٢- Street canyons in Nawroz city are deep, while in Nali city are shallow.

٣- The high plant density in Nawroz city compared to Nali city, protects it from high temperatures, while the city of Nali is hotter, due to the low density of plant areas, which prevents air cooling.

٤- More the ground surfaces in Nali city have concentrations of materials like asphalt that has a low albedo. During the day, these materials absorb heat and gently release it at night. This leads to a rise in temperature during the day and night. But the building surfaces in Nawroz city contain a significant portion of non-reflective building materials. It has high pavement materials that absorb heat slowly and reflects the radiation in the daytime and protect to rise temperature.

## ٥,٢. Mean Radiant Temperature (MRT)

Figure ٨and ٩shows the value of MRT in two neighborhoods.

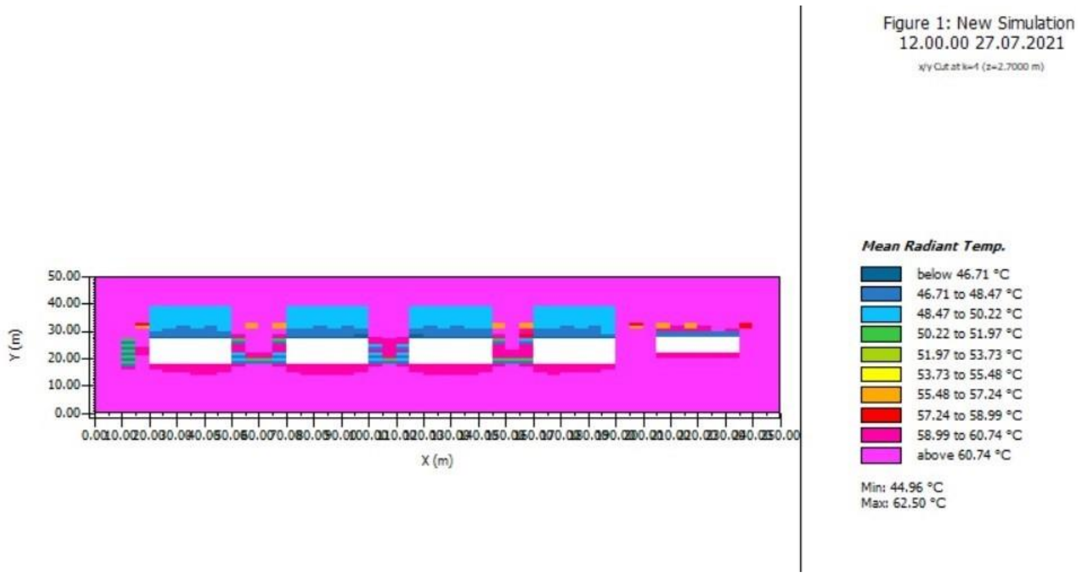



**Figure٨: MRT on ٢٧th of July at ١٢:٠٠ pm in Nawroz city**

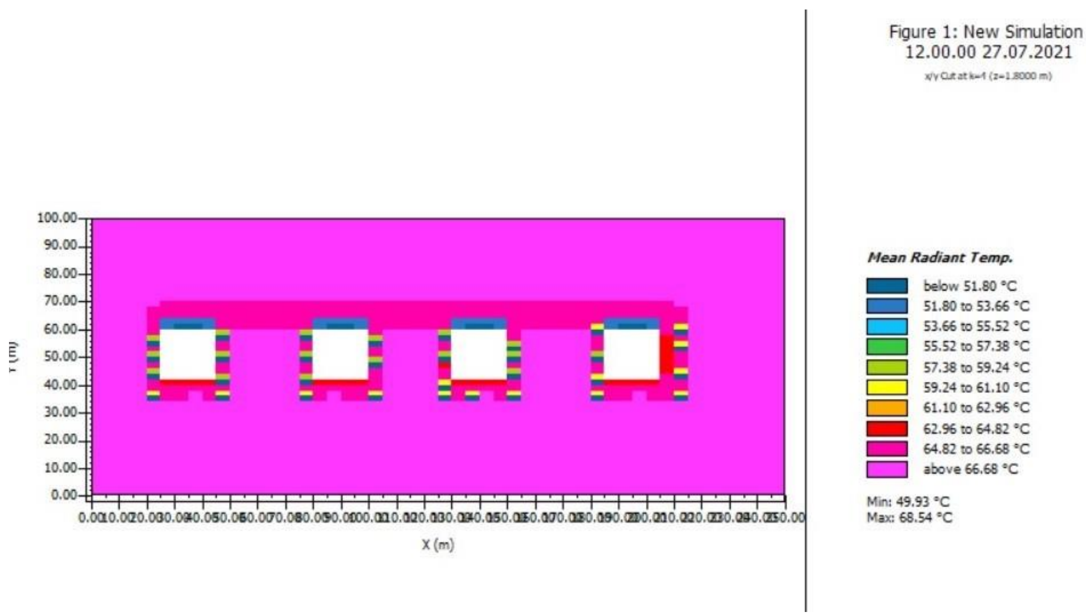



**Figure٩: MRT on ٢٧th of July at ١٢:٠٠ pm in Nali city**

Urban geometry, the sky view factor, shadow patterns, and the width of corridors between buildings are the main factors that affect the MRT. This variable is important in determining how comfortable it is to be outside thermally

The results of simulation reveal that the maximum value of MRT in Nawroz city ٤٤,٩٦°C and the minimum is ٦٢,٥°C.but the maximum value MRT in Nali city ٦٨,٥٤°C and minimum is ٤٩,٩٣°C see Figure١٠.

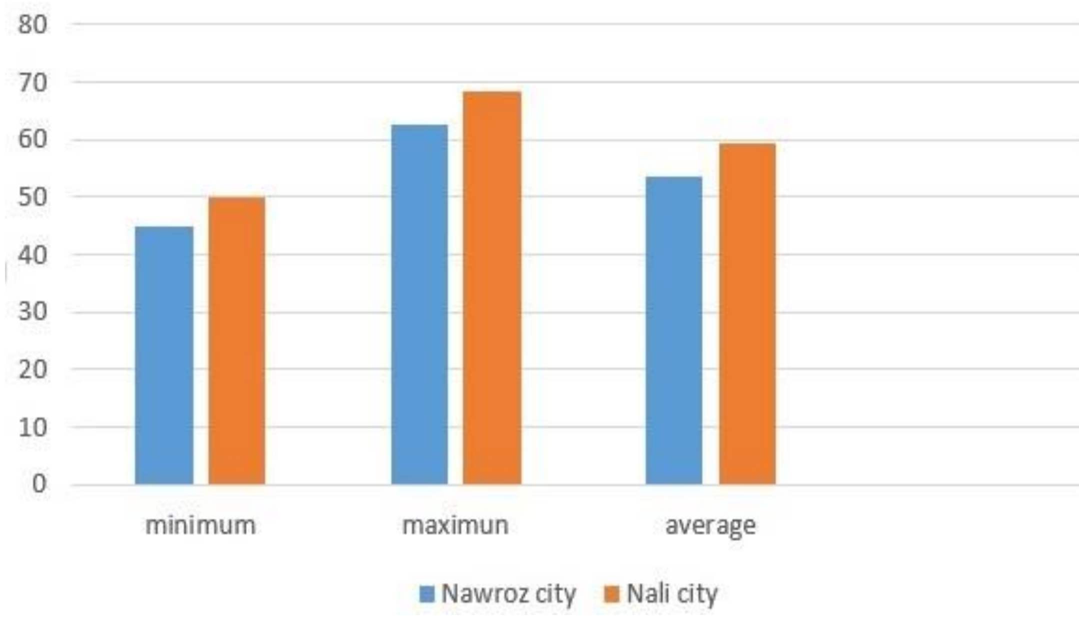



**Figure ١٠: Range of MRT for the two neighborhoods at ١٢ pm on ٢٧th of July**

Locations near buildings with shade and plantings showed a lower MRT than the other study areas in the two neighborhoods. Shadows cast by both buildings and plants are the most effective way to minimize MRT maximum values.

According to simulation results, Tmrt values were highest in Nali city, which can be attributed to the high levels of direct and reflected short-wave radiation, as well as long-wave radiation, released by the surrounding sunny surfaces. Because of the following reasons:

١- The shortage of shadows and the lack of vegetation contribute to increasing the values of Tmrt in Nali city than Nawroz city. Because it decreases the convective heat flow from the sunny building to the ground surfaces, shading is one of the restricted elements of thermal stress. The amount of direct shortwave radiation that directly reaches buildings, the ground, and people is also decreased by shading.

٢- In Nali city, particularly at noon, the space between buildings increases the exposure to sunlight. The sky view factor and the mean radiative temperature during the day have a strong relationship. A high aspect ratio combined with a low sky view factor play an essential role in mitigating MRT in Nawroz city.

٣- Most of the materials used in the Nawroz city site were high albedo materials, but Nali city used low albedo materials, especially in the pavement, this is a reason to high rate of MRT

٤- Narrow streets in Nawroz city offer better building shading than wide streets in Nali city

## ٦. Conclusion

The main conclusions from the paper will be summarized

١-This study demonstrates the urban design measures and strategies in Nawroz and Nali cities that could be used to improve the performance of outdoor thermal comfort.

٢- With both Nawroz and Nali cities, areas close to buildings and covered in shade and plantation have lower temperatures and mean radiant temperatures than other areas.

٣- Because mean radiant temperature is the most important factor determining human thermal comfort, shade is regarded as the greatest approach for achieving it.

٤- Street orientation, canyon geometry, aspect ratio, SVF, vegetation, and pavement materials have a significant impact on both air temperature and mean radiant temperature.

٥-The quantity of heat absorbed by the surfaces of buildings and the ground increases due to a lack of vegetation and shadows, as well as the wide space between them.

٦-Construction materials are crucial in preventing heat transfer from the hot exterior to the cooler interior and maintaining a generally cool interior.

٧-The result simulation parameters did not achieve satisfactory results but Nawroz city is better performance than Nali city due to its performance in urban design measures that were discussed before.

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