

Cooling Effect of Shaded Open Spaces on Long-term Outdoor Comfort by Evaluation of UTCI Index in two Universities of Tehran.

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Abstract

Environmental matters are more complicated. Sustainability of environment requires an integrated approach to decisions making, planning, and management. Therefore, there is a need for a professional and systematic environmental management approach to reducing the consumption of resources. This approach is generally lacking in most universities, and therefore achievement of sustainability becomes much more difficult. This paper focuses on the comparative study of the effects of the sky view factor (SVF) on mean radiant temperature (T_{mrt}) and the thermal indices derived from these parameters in two different universities in Tehran: IUST and University of Amir-Kabir. The outdoor thermal conditions of these campuses because of different levels of greenery in spring and summer create different conditions in terms of thermal comfort or thermal stress. In this paper, environmental data by the experimental approach (field measurement) and they were analyzed by static manner. The authors calculated UTCI by the UTCI calculator as thermal stress in the spring and summer of 2015. Subsequently, by decreasing the sky view factor by a value of 0.4 (increasing the shaded spaces), the mean radiant temperature will decrease by 3.04°C. These changes of T_{mrt} effect on the reduction of UTCI values. Comparison of UTCI index in two campuses illustrate that on average, there is a 1.28°C difference on the UTCI index and in September the IUST campus is 2.72°C cooler on the UTCI scale. The results of this study give correct guidelines to designers to create much more shaded open spaces to reach sustainable environment in universities.

Keywords: University Campuses, Shaded Open Spaces, Thermal Comfort, UTCI.

1. Introduction

The quality of life for people in urban areas is interaction outcome of people with the urban environment (Das, 2008). Environmental quality is an abstract concept resulting from both human and natural factors operating at different spatial scales. Mentioned quality deeply depends on the thermal comfort of green public open spaces in an urban context. In this field, there are some different attitude in definition of thermal comfort (ASHRAE Standard, 1966; Heijis, 1994; Benziger, 1979; Hensen, 1990; Limb, 1992; McIntyre, 1980; Olgyay, 1963; Givoni, 1998). But in brief definition, thermal comfort can be defined as 'that condition of mind which expresses satisfaction with the thermal environment' (ISO, 1984). The outdoor thermal comfort is generally impacted by the built environment e.g., anthropogenic heat, coverage material of ground surfaces, and shading by both green spaces and man-made objects. During hot summer days and some spring days, high outdoor temperature due to intensive solar radiation is the main factor affecting discomfort sensation. Daytime outdoor heat stress can be mitigated by maximizing shading, reducing the absorption of heat into buildings and the ground, and by increasing evapotranspiration cooling. Shading can be increased by increasing either the building density or a number of trees (Lindberg & Grimmond, 2011). SVF is defined as "the ratio of the amount of the sky which can be seen from a given point on a surface to that potentially available (i.e.,

the sky hemisphere subtended by a horizontal surface)" (Oke, 1987). Currently, by cities development, the Urban Heat Island phenomena is increasing and effect of UHI on human health, energy consumption and also the air quality is considerable. By this means, architectural tools and forms have key benefits in mitigating the UHI effect and also a climatic effect on human and pedestrians comfort sense. (Taleghani et al., 2015; Ali-Toudert et al., 2006; Ahmed, 2003; Johansson, 2006). Universities, like cities, have multifaceted activities and operations with possibly important environmental effects (Alshuwaikhat, 2008). University and its built environment have a significant local socioeconomic impact, going far beyond the university itself, due to their scale. This is also because of the number of people using its services not only for educational and study goals but also living (dormitories) and participating in a wide range of cultural activities within the campus (Chung, 2014). The thermal comfort of people who spend their time in outdoor conditions is one of the issues that affect the quality and quantity of outdoor activities. Thermal comfort in the outdoor environment is mainly related to thermophysiology, i.e. physiology and the heat balance of the human body (Hoppe, 2002). Therefore, in this study, the effect of SVF on UTCI considered as the novelty of the research. This study seeks to illustrate the practical application of shaded open spaces and low sky exposed built environment on the thermal comfort with reliable thermal index (UTCI) for open

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spaces consequently the results of this study make designers aware of the advantage of creating shaded open space to enhance the thermal condition of users. The present study has been conducted in the spring and summer seasons of 2015 but fall and winter season also should be done and this is recommended as future studies.

2. Research background

Earlier researchers illustrated that lower daytime Ta (Cool Island) and higher nighttime TA (heat island) in urban canyons are the affected by lower SVF on the thermal comfort condition. (Johnson, 1985; Yamashita et al.,1986; unger, 2004; Svensson, 2004; Zhu et al.,2013; He et al.,2015; Cheung et al.,2016). Yan et al.,2014). In Beijing carried out a study by means of the effect of landscape parameters such as SVF effect and environmental thermal condition. they showed China showed an association between the daytime Ta and SVF in an urban context, which means that increasing SVF increases daytime Ta; the temperature regime is the inverse at night. As the same way there some studies that showed there is a close correlation between Ta and SVF (Svensson, 2004; Yuan & Chen, 2011; Bourbia & Awbi, 2004). But according to some other studies, Ta and SVF have a weak correlation (Yamashita et al., 1986; Upmanis & Chen,1999; Rzepa, 2009). Some other studies have shown a strong relation- ship between SVF and the measured net long wave radiation, some experimental studies demonstrated that the SVF alone is insufficient in presenting the complex thermal phenomena (Eliasson & Holmer,1990; Eliasson 1996; Niachou et al.,2008). The level of Sky exposure is ascribed to the less solar radiation to penetrate into urban canyons with low SVF during the day, thereby affecting the and mean radiant temperature which, in turn, determine the comfort level in outdoor areas. (Givoni, 1998). Heat stress events are generally associated with clear sky conditions and high air temperature (Ta), which give rise to the high radiant heat load, ie mean radiant temperature (Tmrt) (Ka-Lun Lau et al., 2014). IUST and Amir-Kabir university campuses with different levels of shaded places have different thermal environments. Recently, some studies were conducted regarding the shading effect on outdoor thermal comfort. (Shahidan et al., 2012; Ng E et al., 2012; Hamada & Ohta, 2010; Masmoudi & Mazouz, 2004; Oliveria et al.

2011; Lin et al. 2010) and because of the important effects of solar radiation as fundamental factors of Tmrt in thermal indices like PET, recently some studies in environmental settings have focused on these parameters (Linderg & Grimmond 2011; Monteiro et al. 2012; Papanastasiou et al., 2010; Lindberg et al., 2013; Thorsson et al.,2014; Ali-Toudert & Mayer, 2006). But some studies were conducted. regarding the effect of Tmrt in thermal stress and environment thermal conditions in university campuses (Wong et al., 2007; Wong & Jusuf, 2008; Geng et al., 2013) . There some few studies in Iran that are related to the outdoor thermal comfort (Tahbaz, 2007; Behzadfar & moanm,2012; Heidari et al.,2013; Ghazizadeh et al.,2012;feizi et al., 2015). Ghazizadeh et al (2012) proposed some guidelines by simulation method to design open spaces more comfortable. Therefore they have stimulated the residential complex in different settings to reach the best thermal conditions in terms of mean radiant temperature, sky view factor (SVF), shading level.Heidari et al (2013) compared different thermal indices to determine a more accurate thermal index for the outdoor condition. In this study, they define each thermal index and its thermal sensation category. By this means, they compared the outcomes of the questionnaire and the thermal sensation category of the thermal indices. The result of the comparison demonstrates that physiological equivalent temperature (PET) is an appropriate and accurate thermal index for evaluating the thermal condition of open spaces. Behzadfar and monam(2012) by comparison of the different SVF values in different urban parks in Tehran(capital city of Iran) with the air temperature, globe temperature and mean radiant temperature(Tmrt).they showed that SVF values are more correlated to the Tmrt than the air temperature and globe temperature in the urban park. Shade places seem to be more comfortable places and in previous studies and they have evaluated the effect of different factors of the outdoor thermal comfort on each other not on thermal indices, therefore in this study shadow effect of the built environment will be measured on university campuses to Show correlation between SVF values and Tmrt and PET to determine the SVF effects on the thermal sensation based on PET thermal index.

Table 1
Analyses of Tehran’s thermal conditions based on ASHREA STANDARD (Heidari, 2009).

Warm		Slightly warm		Neutral		Slightly cool	
Jul 21	Jul 6	Jul 6	Jun 22	Jun 22	Apr 21	Apr 21	Apr 4
Neutral		Slightly warm		Warm		Hot	
Oct 22	Sep 23	Sep 23	Sep 6	Sep 6	Aug 21	Aug 21	Jul 21
Cold		Very cold		Cold		Slightly cool	
Apr 4	Feb 20	Feb 20	Jan 5	Jan 5	Dec 6	Dec 6	Oct 23

3. Research methodology

3.1 Study area

This study was done in Tehran (51° 20' E, 35° 41' N, and altitude =1368m), Tehran is the capital city of Iran. With a population of around 9 million in the city and 16 million in the wider metropolitan area. It is Iran's administrative, economic, and cultural center as well as the major industrial and transportation center of the region and it is situated at the foot of the towering Alborz mountain range. Tehran is a cosmopolitan city, with great museums, parks, universities. Iran University of Science and Technology (Elm o sanat-e- Iran - IUST) is situated in the eastern part of Tehran with 420000 square meters' area. The majority of the campus of IUST is covered with green spaces and due to much more shaded open spaces, the outdoor thermal conditions of this campus has a better condition due to its surrounding urban context. the Amir-Kabir University of Technology is also one of the important universities of Tehran, but the campus of this university does not have as much shaded open spaces, so it can be compared with IUST University in terms of outdoor thermal comfort conditions, and its related parameters like SVF and Tmrt and thermal index UTCI.

3.1.1 Climate of Tehran

Using data from twenty years of Ta observations in Tehran, it can be determined that: from 15 January to 1 March, the thermal comfort conditions of the city is very cold, but its conditions from March to mid-April, as well as from the second half of December to 15 January are cold. From 15 April up for two weeks, the conditions are a little cold. Before the beginning of December for about a month and a half, it is a little cold. People enjoy the conditions in May and June and would prefer the conditions to remain at these temperatures. This is also the case in October. The first half of July experiences semi-warm conditions and in the second half, it experiences

warm conditions. But the thermal condition of August is very warm and according to this scale, the first half of September is warm and the second half experiences semi-warm conditions (Heidari 2009).

3.2 Materials

In this paper, 20 points of these two campuses (faculty zones) were selected to be assessed in terms of thermal comfort of the temperature of Tehran. Meteorological data (air temperature, wind velocity, Relative humidity) were measured in 15th of each month (March 21 until September 22 of 2015). Data logger (Lutron LM-8000) was used for placing air temperature (Ta) and Relative humidity (RH) and wind velocity (V) in one-hour intervals automatically at 1.10 of height from 8 to 18:00, for the spring and summer seasons of 2015. As next step, the data were averaged by Excel software. Spherical photographs for the calculation of SVF were taken with a Hero-3 (fish-eye lens) camera. These photos were analyzed according to sky texture and color codes. Ten points were selected from the campus of IUST (faculty zones) in terms of sky view factor (SVF) and the aim was to have a wide range of this factor. These spherical photos were taken on the 20th August at 11-12am. Point 4E (Area of cafeteria and self-service for teachers) with 0.161 as the lowest SVF and 1E (Faculty of Physics) with 0.633 has uppermost SVF score and the average SVF on this campus is 0.3305. As with the campus of IUST, Ten points in the campus (faculty zone) of Amir-Kabir University were selected. Selection of these points was according to the SVF and the aim was to have a wide range of SVF values. The photos were taken on the 20th August at 1-2 pm. Point 1A (Area between Faculty of Electrical and Mechanical Engineering and Oil Engineering) with 0.437 has the lowest SVF and 4A (front area of Exhibitions) with 0.918 has the uppermost SVF and the average SVF on this campus is 0.7206.

Table 2

Average of meteorological data spring and summer seasons over 5years (2011-2015) of Tehran.

	Vapor pressure hpa	Wind velocity m/s	Relative humidity %	Dew Point (°C) (f)	Air temperature (f)	Air temperature (°C)
Mar21- Apr20	879.500	5.64	15.47	-3.45	66.938	19.41
Apr21- May21	878.900	6.19	12.05	-4.48	80.294	26.83
May22- Jun21	878.200	4.35	10.30	-1.58	92.782	33.74
Jun22- Jul22	875.500	4.35	10.34	0.51	98.132	36.74
Jul23- Aug22	850.100	3.74	10.33	-0.38	95.864	35.48
Aug23- Sep22	881.200	3.9	17.48	2.87	86.522	30.29



Fig. 1. Metrological data logger (Lutron LM-8000).

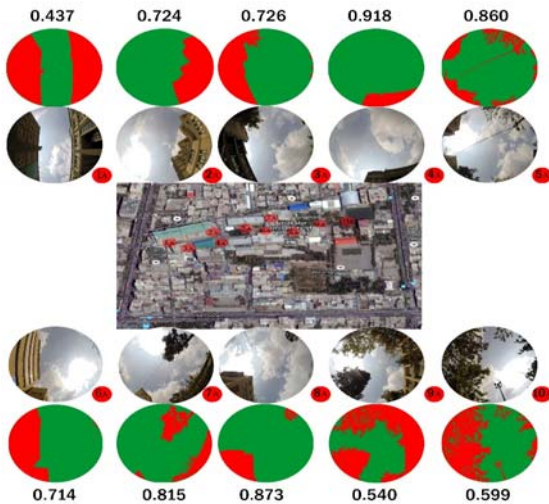


Fig. 2. Study location: Amir-Kabir University from wikimapia (<http://wikimapia.org>). Spherical photos were taken using Hero-3 fish eye lens camera and visual categories of photo by Spatial pyramid software and SVF is derived from the Rayman model software.

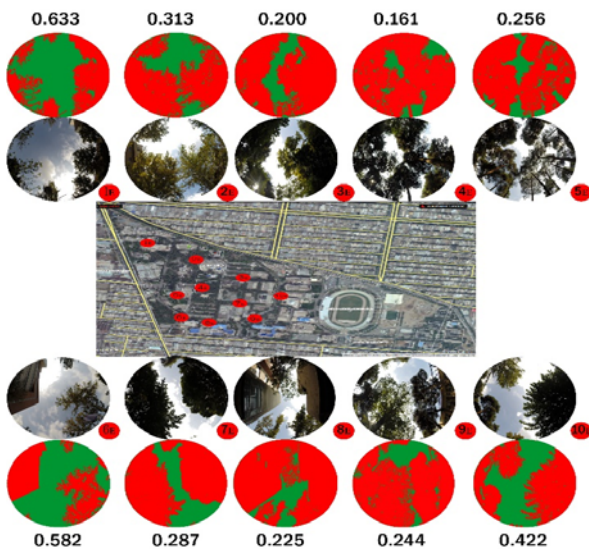


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3.3 Workflow

The UTCI calculator was used to calculate the Universal Thermal Climate Index (UTCI) based on the sky view factor of the campuses. The outdoor thermal comfort of these campuses (faculty zone) will be discussed and compared in the following sections of this paper. The effect of Tmrt based on SVF is derived from the Rayman model. Fig.3 shows the procedure of investigation in long-term thermal comfort on university students in the

spring and summer seasons by measuring the thermal comfort index (UTCI) by the UTCI calculator. The SPSS software and Excel were used to compare and discuss on the UTCI, Tmrt, and SVF.

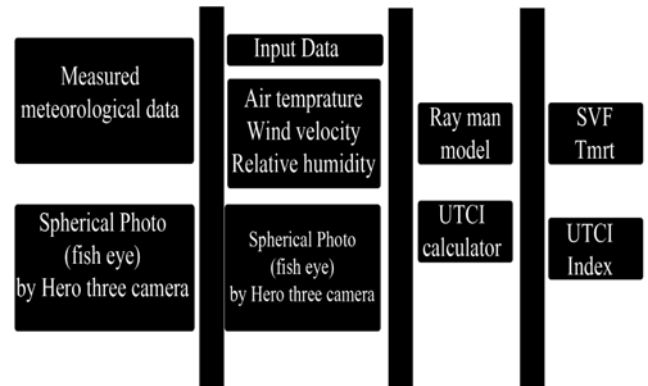


Fig. 4. Procedure of investigation of thermal comfort and thermal stress on university campuses based on Tmrt and SVF.

3.3 Calculation of UTCI as heat stress index

Heat stress can be measured by the UTCI category for heat stress but this thermal index (UTCI) is more usually known for thermal comfort and heat stress and it is a validated index for evaluation of heat stress conditions. (Psikuta et al., 2012; Jendritzky et al., 2007; Brode, 2013). Heat stress can occur when air temperature, radiation, humidity, and the wind interact to produce a tendency for body temperature to rise (Motamedzade & Azari, 2006; Lafortezaa et al., 2009). A range of measures exists which can mitigate heat stress in urban environments, such as increased amount of green spaces, e.g. city parks, urban woodland, street trees, rooftop gardens and vertical greenery on buildings (Lafortezaa et al., 2009). In this sense, green spaces are particularly beneficial to an improved urban microclimate through shading and evapotranspiration, which in turn help to create comfortable outdoor settings for people as well as the potential of reducing symptoms in thermal discomfort under heat stress conditions (Nikolopoulou & Steemer, 2003; Shashua-Bar and Hoffman, 2003; Lafortezaa et al., 2009). The universal thermal climatic index (UTCI) was developed for characterizing thermal stress. It is an equivalent temperature for a given combination of the wind, radiation, humidity and air dry bulb temperature (Ahmed et al., 2014). By importing meteorological data such as air temperature (T_a), wind velocity (v), mean radiant temperature (T_{mrt}) and vapor pressure (VP), the UTCI index can be easily calculated by the UTCI calculator that is freely available by its authors (UTCI.org,2015).

Table 3
Universal Thermal Climate Index (UTCI.org,2015)

UTCI(°C) range	Stress category
Above +46	Extreme heat stress
+38 to +46	Very strong heats tress
+32 to +38	Strong heat stress
+26 to +32	Moderate heat stress
+9 to +26	No heat stress
+9 to 0	Slight cold stress
0 to -13	Moderate cold stress
-13 to -27	Strong cold stress
-27 to -40	Very strong cold stress

4. Results

4.1 Sky view factor (SVF)

4.1.1 SVF of University of Amir-Kabir

The range is SVF value is $0.437 < SVF < 0.918$ and 70% of the selected points have an SVF value of more than 0.7 and according to the average SVF (0.7206), 72% of ground surfaces on this campus (faculty zones) are receiving direct solar radiation and students who are on this campus are more prone to getting radiant heat and exposure to thermal stress. This will be discussed further.

4.1.2 SVF value in the campus of IUST

The range of SVF value is $0.161 < SVF < 0.633$ and 60% of the selected points have an SVF value of more than 0.3 and according to the average of SVFs (0.3305), 33% percent of ground surfaces on this campus (faculty zones) receiving direct solar radiation and 67% of the faculty zone of the IUST are in the shadow condition and students who are on this campus are in a more thermally comfortable zone. This will be further discussed.

4.1.3 Comparison

Regarding the different levels of shaded open spaces of these two universities, there were two different levels of SVF value which were mentioned. The average SVF in Amir-Kabir University is 0.7206 and in IUST 0.3305. different SVF value of these two universities creates different shadow patterns in the campuses. Consequently, the students have different opportunities to adapt their thermal behavior with their environment, so students have more adaptation opportunity on the campus of Elm o Sannat (IUST) university due to the abundance of shaded open spaces. and low SVF values.

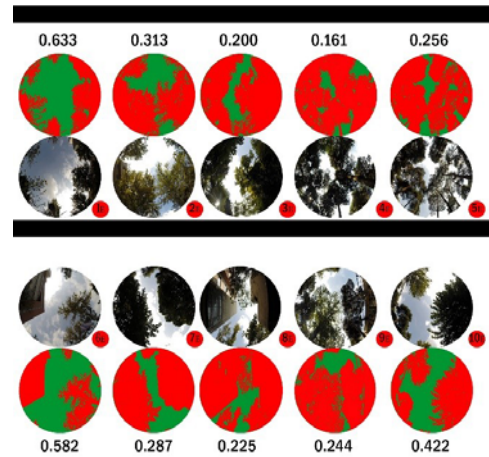


Fig. 6. Spherical photo (fish-eye lens) of campus of IUST . Visual category of spherical photos based on texture and color codes and numerical analyses by the Rayman model software.

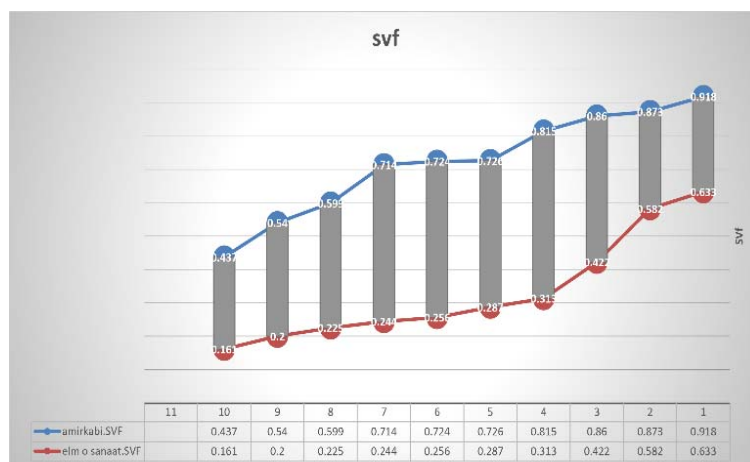


Fig. 7. Numerical comparison of SVF values in Amir-Kabir and IUST campuses.

4.2 Mean radiant temperature (Tmrt)

4.2.1 Tmrt in the campus of University of Amir-Kabir

Tmrt - as an indicator of the heat stress - is very important in high Ta and in warmer and hotter (spring and summer)

seasons. With high Tmrt values, the role of shaded open spaces in mitigating heat stress become more obvious. In

these two campuses (faculty zones) because of the different SVF values, there are different Tmrt values in the fixed metrological data. In each season by increasing T_a , the Tmrt also increases and this also changes according to the season. Tmrt has been analyzed in 10 points of both campuses for each month (6 months of spring and summer) that 60 numbers of Tmrt have been derived from this calculation Figure 7 will demonstrate that the Tmrt value range is $34.3^{\circ}\text{C} < \text{Tmrt} < 55.4^{\circ}\text{C}$ and the highest

Tmrt occurs in July whereas the lowest one occurs in April. 34.3°C is related to the SVF of 0.437 and 55.4°C is related to the SVF value of 0.918 and also according to the graph, quick changes in SVF, make sudden changes in Tmrt.

Numerical analysis of Tmrt demonstration that 45 numbers (75%) of Tmrt of 60 points has more than 40°C and also 36 (60%) numbers of these points have more than 50°C of Tmrt.

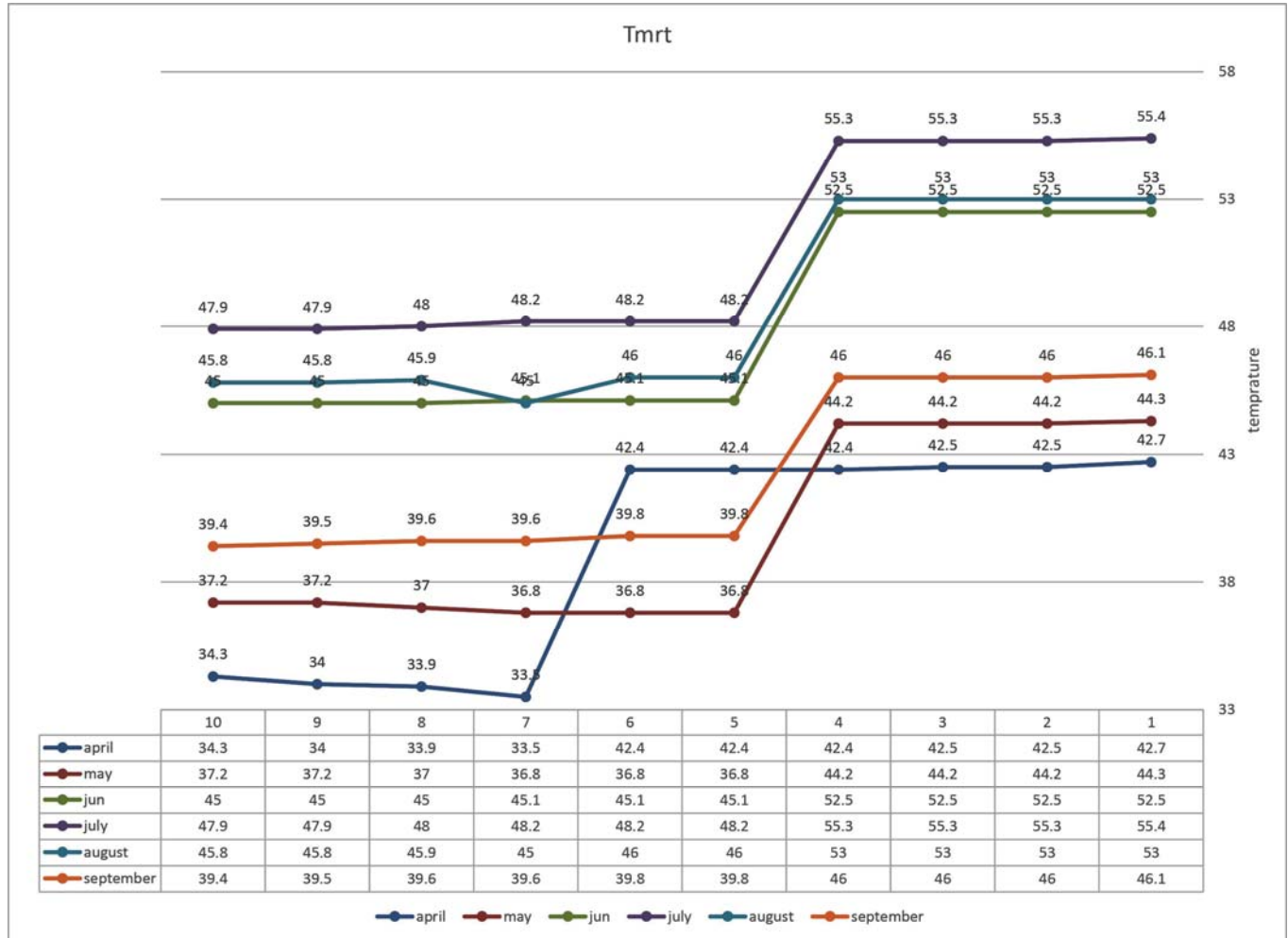


Fig. 8. Tmrt value in the spring and summer of 2015 (March 21-September 22) in the campus of Amir-Kabir.

4.2.2 Tmrt of the campus of IUST

In the campus of IUST (faculty zone) with the more shaded open spaces, the graph of Tmrt grows slowly and gradually gets to its maximum Tmrt value. The range of Tmrt is $28.2^{\circ}\text{C} < \text{Tmrt} < 54.5^{\circ}\text{C}$ and the highest temperatures are related to an SVF value of 0.633 and according to the graph all Tmrt values of the April are less than 30°C and also all points of September are less than

40°C and 9 of 10 selected points (90%) in August have less than 50°C of Tmrt. However, the maximum Tmrt values in both universities are more than 50°C (55.4 and 54.5) but only 5 points of 60 are more than 50°C in comparison with Amir-Kabir University where 12 points are more than 50°C . According to the following bar chart, 33 (55 %) points of the 60 have more than 40°C of Tmrt and only 12 (20%) of 60 points have more than 50°C of Tmrt.

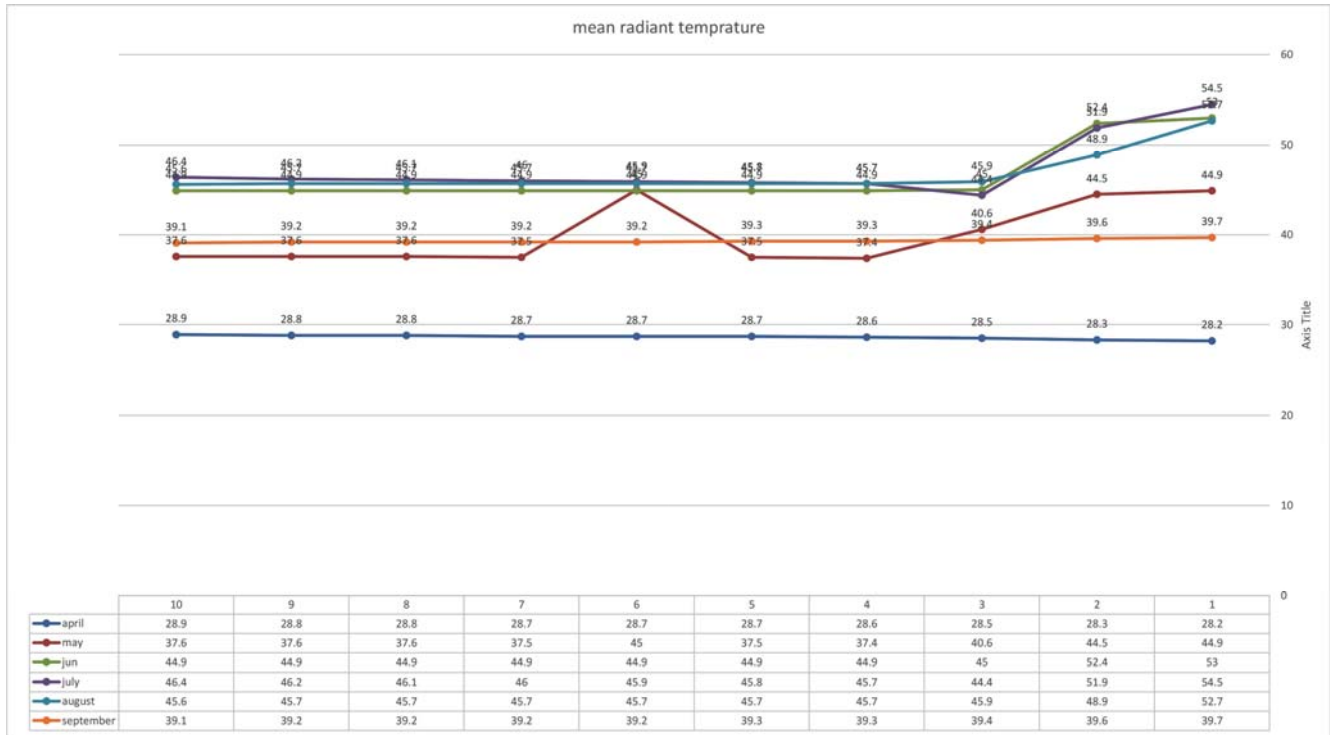


Fig. 9. Tmrt value in spring and summer of 2015. (March21 - September 22) in the campus of IUST.

4.2.3 Comparison

The calculation of an average of 6 months measured meteorological data to calculate the Tmrt in both of these two universities highlights that the average Tmrt in the campus of Amir-Kabir is higher than IUST. Because of almost equal measured metrological data for the both campuses, these differences in Tmrt value are related to the difference in SVF value. This graph has been drawn based on the average Tmrt for each month according to 10 selected points in each of the two campuses. However, at both of these universities, there are points that have more than 50°C of the Tmrt values but the average Tmrt of each month shows that there is 3.68°C difference in the apex of the Tmrt. The monthly graph between SVF and Tmrt in spring and summer in the campuses of Amir-Kabir and IUST shows that according to SVF growth, the Tmrt value is also increasing. The following table describes the correlation between SVF and Tmrt by Pearson's Correlation Coefficient in the campus of Amir-Kabir University.

According to the table in every month, there is more than a 70% correlation between SVF and Tmrt and the highest correlation is related to September and the average Pearson correlation is 0.80 which represents a good correlation between these two variables.

Based on the same analysis that has been carried out for Amir-Kabir University, the correlation table of SVF and Tmrt of Elm-o-Sannat campus (IUST) shows that in all months except April, the Pearson correlations are more than 70%. By comparing these two campuses, it can be understood that there is sufficient correlation between SVF and Tmrt to pay more attention to creating more shaded open space in order to the reduction of Tmrt in landscape and urban designing principles to gain a more sustainable environment.

Table 4
Pearson correlation coefficient of SVF and Tmrt in the campus of Amir-Kabir.

	Apr	may	Jun	Jul	Aug	Sep
Pearson Correlation	-.805**	0.785*	.811**	.823**	.797**	.825**
SIG (2-tailed)	.005	0.007	.004	.003	.006	.003
N	10	10	10	10	10	10

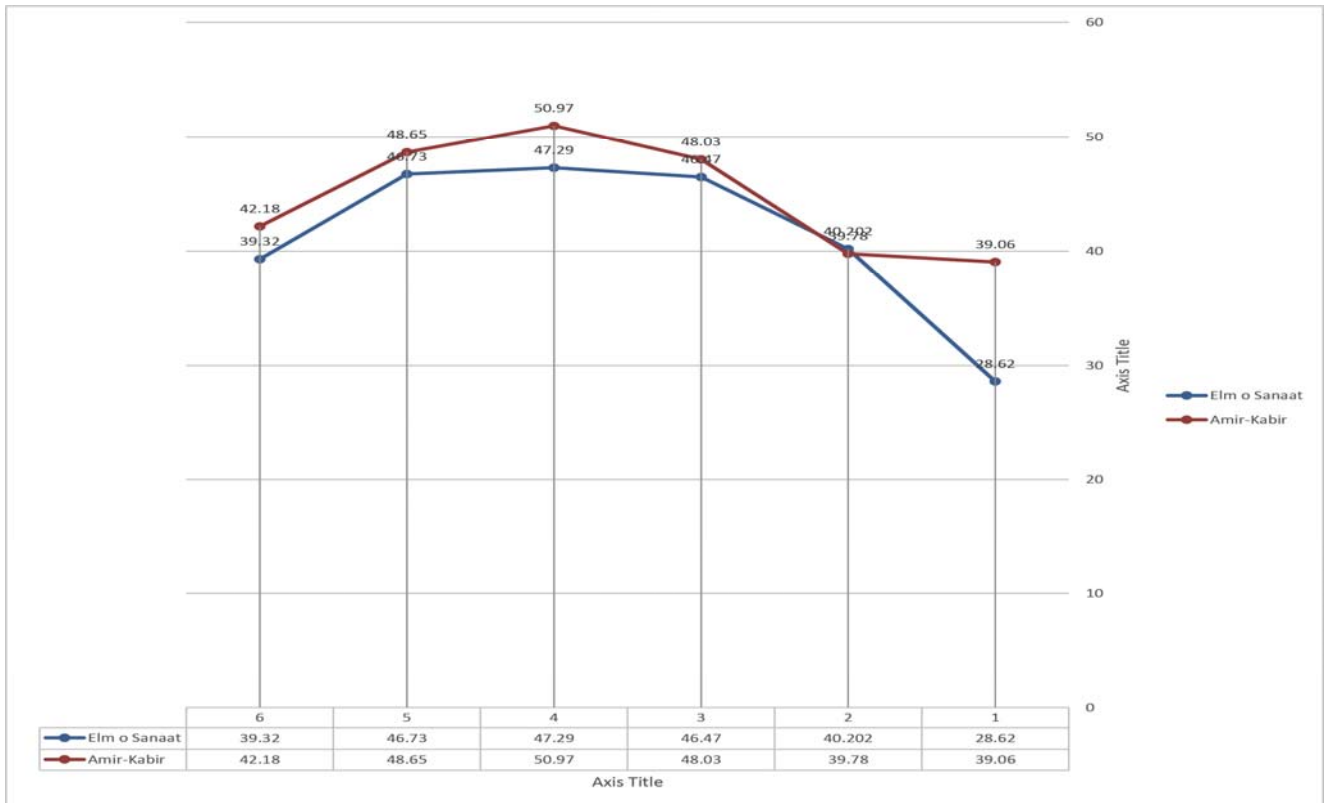


Fig. 10. Tmrt Comparison of two campuses based on the average of Tmrt for each month.

Table 5
Pearson correlation coefficient of SVF and Tmrt in campus of IUST

	Apr	may	Jun	Jul	Aug	Sep
Pearson Correlation	-.991**	0.728*	.903*	.812**	.869**	.992**
SIG (2-tailed)	.000	0.017	.000	.004	.001	.000
N	10	10	10	10	10	10

4.3 University of Amir-Kabir

4.1 Universal Thermal Climate Index (UTCI) of the campus of Amir-Kabir

Because of the high levels of temperature in the mean radiant temperature scale and also high levels of discomfort conditions, another thermal index has been used to describe heat stress levels, in more detail that of the UTCI index which measures the heat stress condition. Numerical analyses of the measured UTCI according to the UTCI heat stress classification, show that April and May experience no heat stress conditions and that June, July and August experience strong heat stress and

September experienced moderate heat stress conditions. It should also be mentioned that 4 points in July experience very strong heat stress conditions and that they occur with high levels of SVF (more than .08).

4.3.2 SVF-UTCI

According to Fig 18, in all 6 months, a higher UTCI is related to higher SVF values and the very strong heat stress occur with SVF values that are higher than 0.8 in July and in other month's better thermal conditions in terms of heat stress are related to lower SVF values. According to the chart, in all 6 months, the points that have an SVF values of more than 0.8 SVF also have higher UTCI.

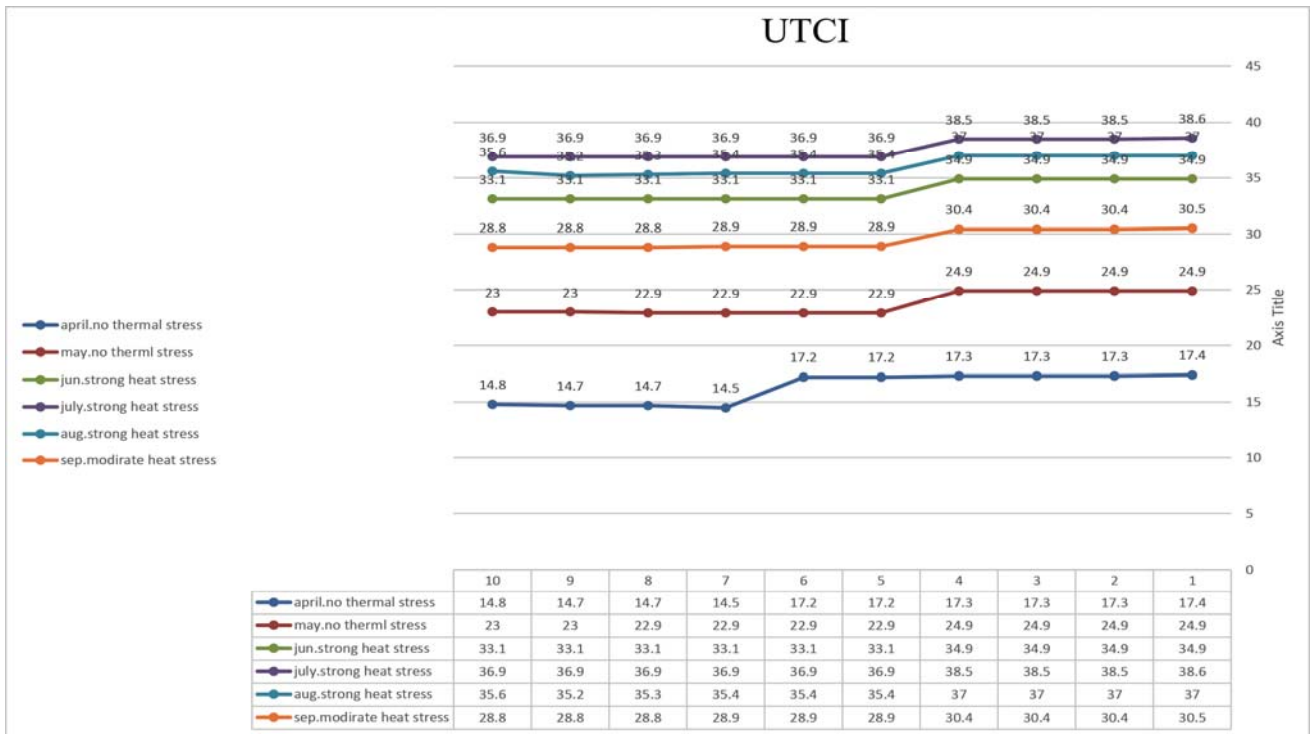


Fig. 11. Monthly diagram of UTCI based on their SVF changes.

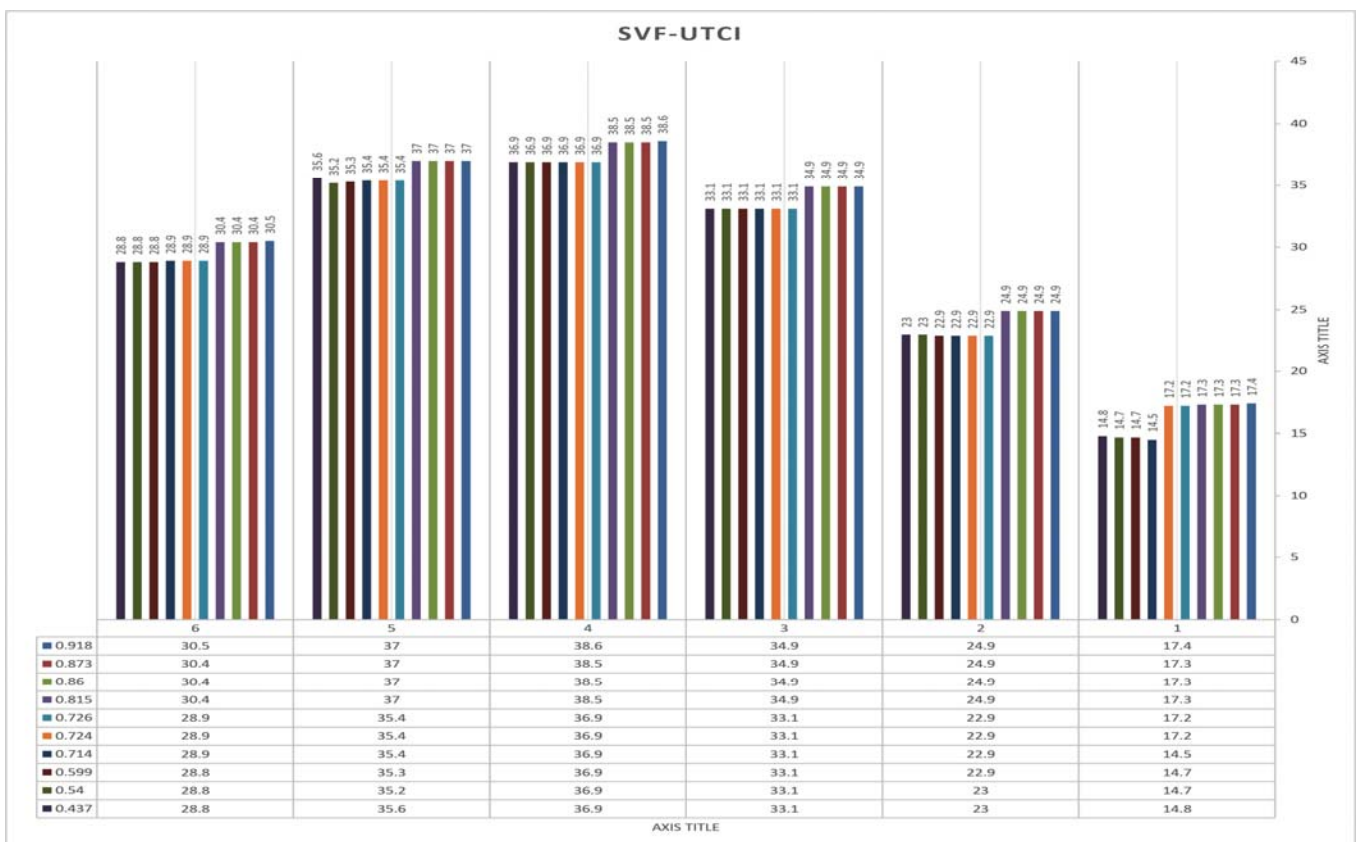


Fig. 12. Monthly analyses of UTCI Progression based on SVF value.

4.3.3 Tmrt –UTCI

Tmrt as an important component of heat stress has been analyzed with UTCI in one chart to compare how these two are related to each other.

The Tmrt and UTCI have been analyzed in 10 selected points and in each column Tmrt and UTCI has been analyzed separately according to the month. The following chart shows that the highest UTCI is related to the highest Tmrt for example: highest SVF (0.918) is related to the column one and in this column all Tmrt and UTCI have been displayed based on their month and according to the column the highest Tmrt is related to the highest SVF and also the highest UTCI is related to the highest SVF and Tmrt. So mitigating the mean

radiant temperature is an important issue. Greenery and green open spaces with their shadows create an environment with less exposed surfaces to directed solar radiation and fewer radiation fluxes with long and short waves and in addition, the shadows can create more opportunity to adapt the user's behavior with their thermal environment. Because of less green spaces on the campus of Amir-Kabir University, 60% of the points have more than 50°C temperature, so hot surfaces with fewer shadow patterns in the environment create unusable open spaces in this university.

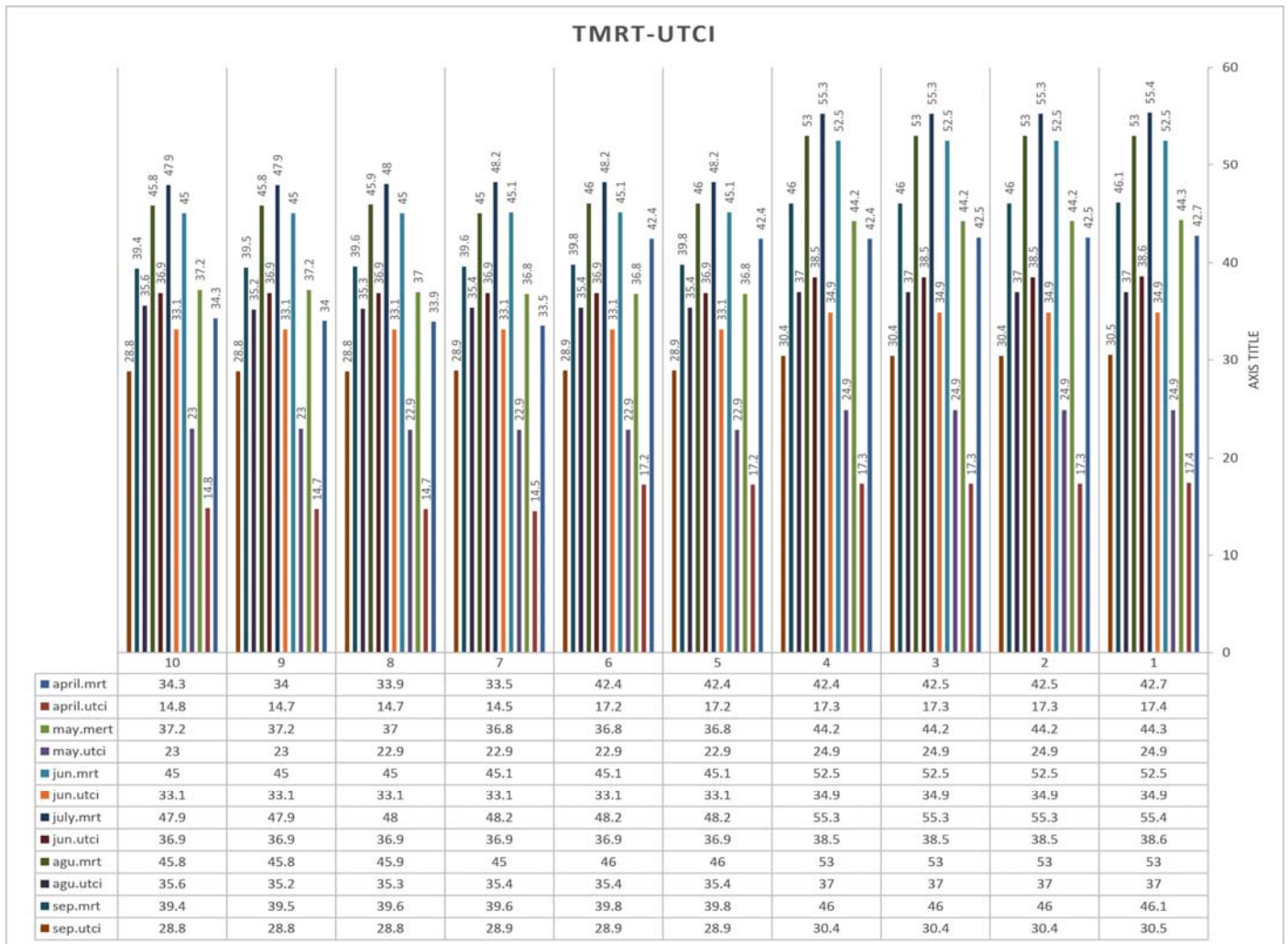


Fig. 13. Numerical analyses of UTCI with their related Tmrt for each month in based on SVF value.

4.4 IUST

4.4.1 Universal Thermal Climate Index (UTCI) of the campus of IUST

Because of the high level of discomfort condition, the UTCI index is used to describe in more detail the thermal conditions of this campus; May and April experience no

heat stress conditions, June, July, and August experience strong heat conditions and September experienced moderate heat stress.

In the following chart, the UTCI condition has been described monthly with their selected point.

4.4.2 SVF-UTCI

The following chart describes the UTCI growth in specific SVF values for 6 months and it shows that the points which have lower SVF values have a lower temperature in the UTCI scale and very strong heat stress occurs in the points that have higher SVF values and it is noticeable that the UTCI temperatures are steady in the points that are lower than an SVF value of 0.5 and the points with an SVF value of 0.633 in all 6 months have the highest temperature.

4.4.3 Tmrt –UTCI

Based on the following chart, the highest UTCI is associated with the highest Tmrt which happens in the highest SVF value. Analyzing Tmrt and UTCI in the 10 selected points with their related month in integrated numerical analyses show that high SVF and clear sky conditions are much disposed to be in the stress condition and their thermal conditions are much more variable. According to the chart, maximum Tmrt of a point that has an SVF value of 0.161 is in July with 45.4°C of Tmrt and its related UTCI is 36.5°C, and also the maximum Tmrt of the point 1 which relates to an SVF value of 0.918 is in July which has 54.5°C of Tmrt with 38.4 UTCI.

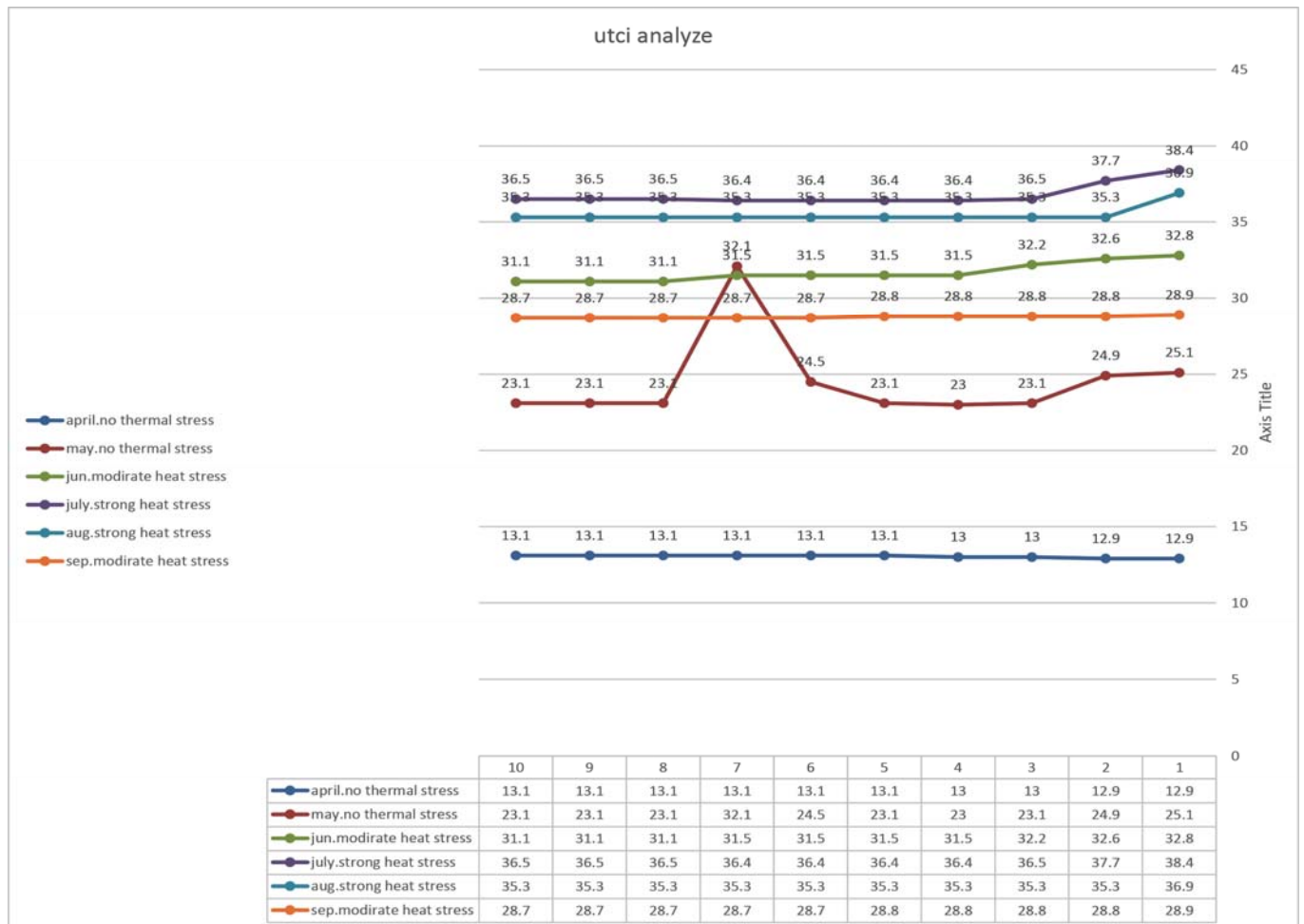


Fig. 14. Monthly diagram of UTCI based on their SVF changes.

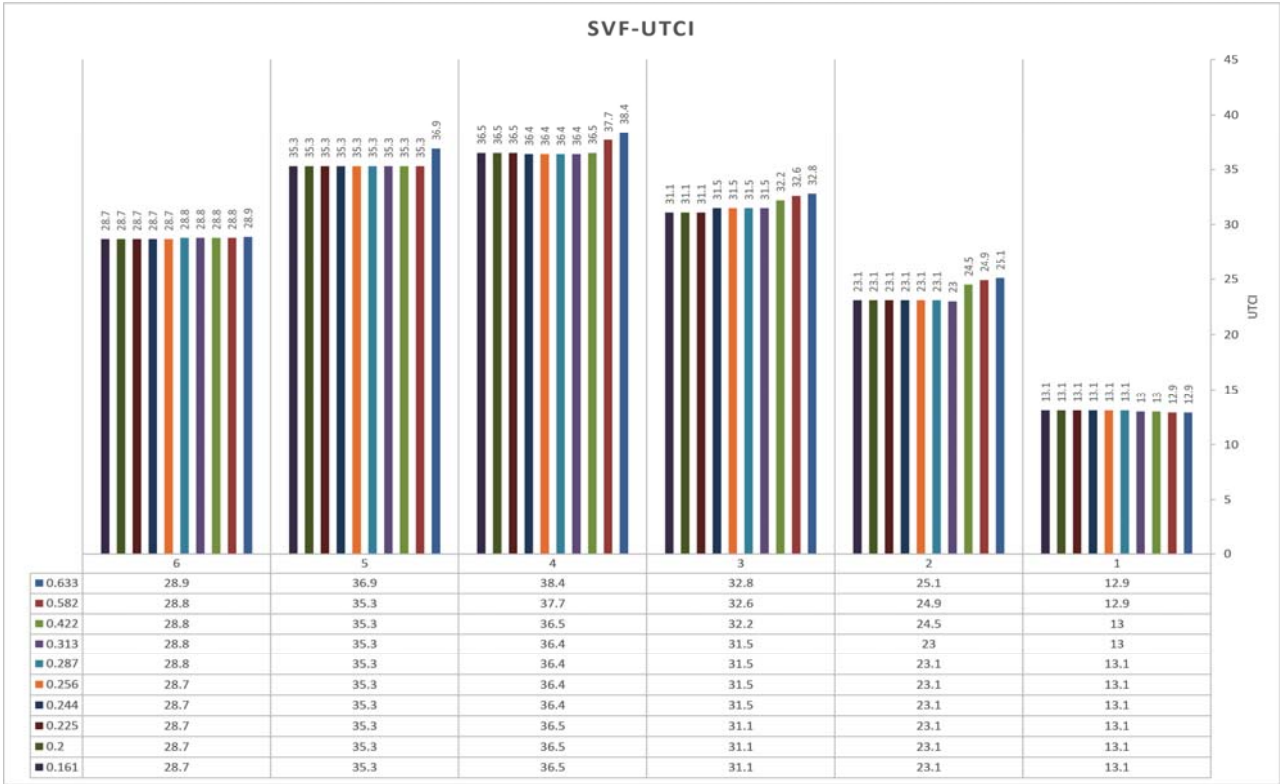


Fig. 15. Monthly analyses of UTCI Progression based on SVF value.

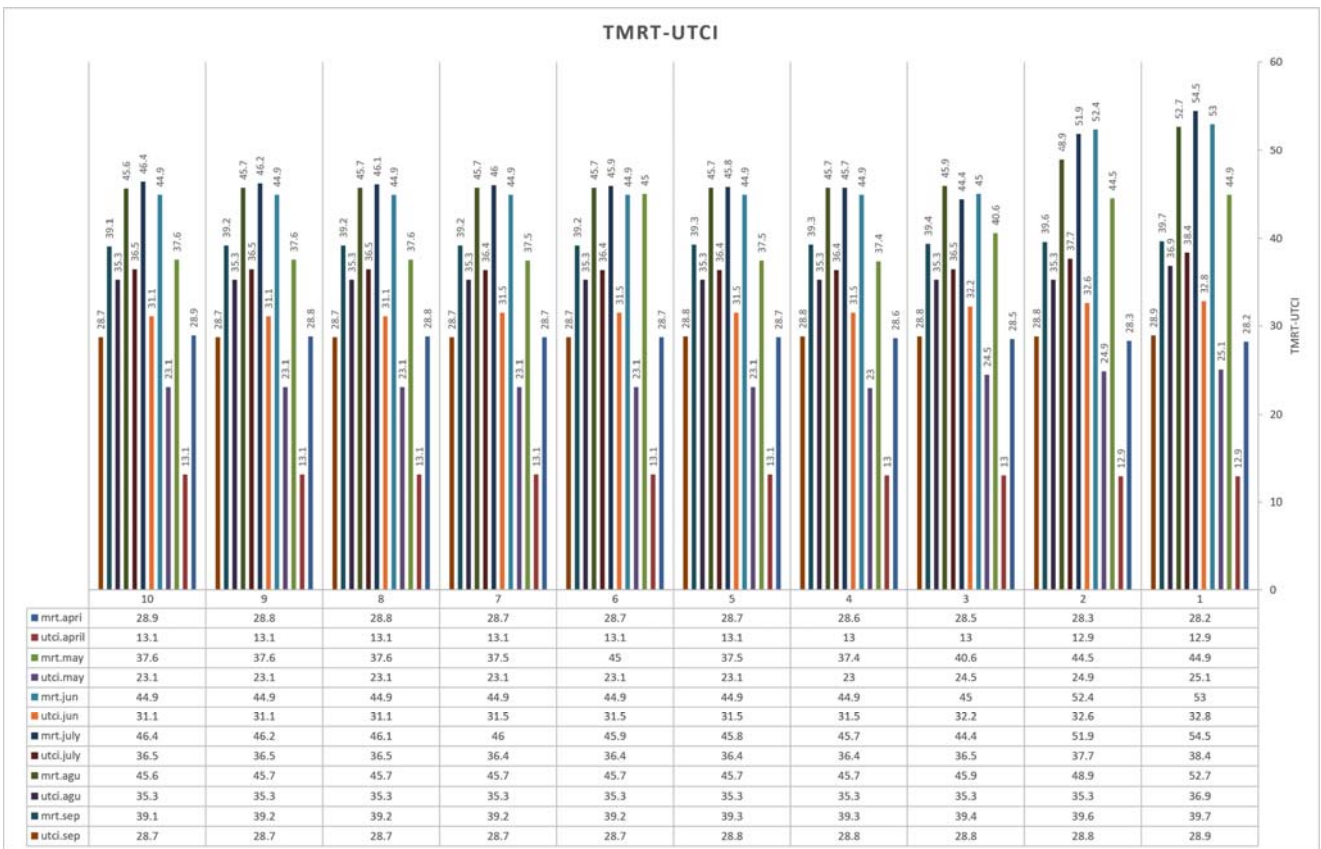


Fig. 16. Numerical analyses of UTCI with their related Tmrt for each month based on SVF value.

4.5 Comparison of UTCI thermal index based on Tmrt and SVF

In environments with high SVF values, Tmrt is the indicator of heat stress conditions and it is one of the important components of the UTCI index. The following graphical diagram highlights the effects of Tmrt changes on the UTCI index. On average, there is a 1.28°C difference in UTCI between the two campuses and the maximum difference is in September by 2.72°C. UTCI index differences in September and April are higher than other months but similar to the UTCI index, whereby increasing the Tmrt, the UTCI value increases as well.

In the following diagram, the relationships of the Tmrt and UTCI have been described by a regression coefficient diagram. In Amir-Kabir University, R² value is 0.9133 and in IUST University, it is 0.945.

All of these numbers (R²) represent the high correlation between Tmrt and UTCI that strongly affect human

thermal sensation. The differences of Tmrt in these two campuses result from the SVF differences and the SVF value of two campuses is related to the greenery. In the following diagrams, the relationships of the Tmrt and UTCI have been described by a regression coefficient diagram. In Amir-Kabir University, R² value is 0.9133 and in IUST University, it is 0.945. Likewise in Amir-Kabir University, the UTCI index and its relationship with Tmrt and their R² is 0.8754 and in IUST is 0.9712.

All of these numbers (R²) represent the high correlation between Tmrt and thermal indices in comfort and stress scales and changes in Tmrt will strongly affect human thermal sensation. The differences of Tmrt in these two campuses result from the SVF differences and the SVF value of two campuses is related to the greenery.

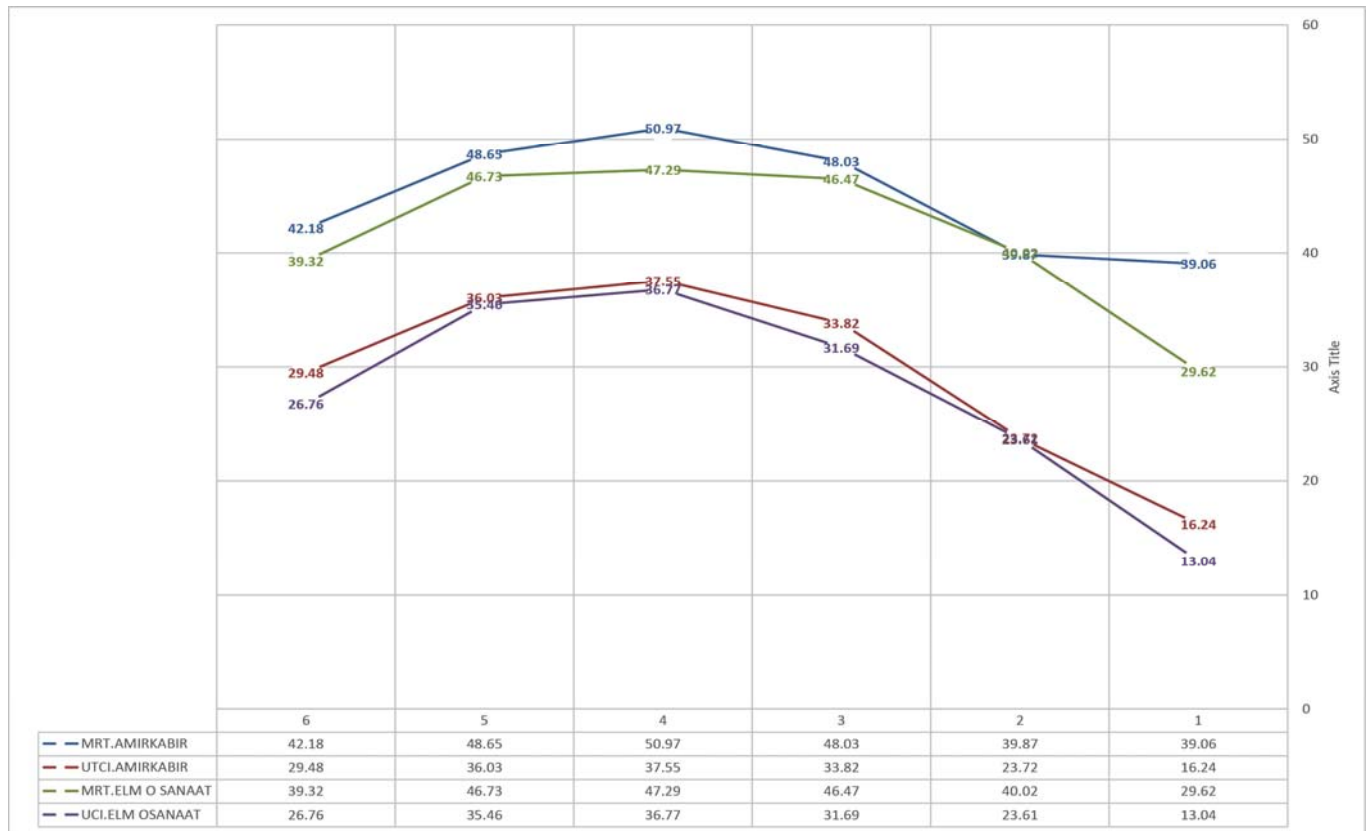


Fig. 17. Comparison of UTCI of both campuses in comparison of their related Tmrt.

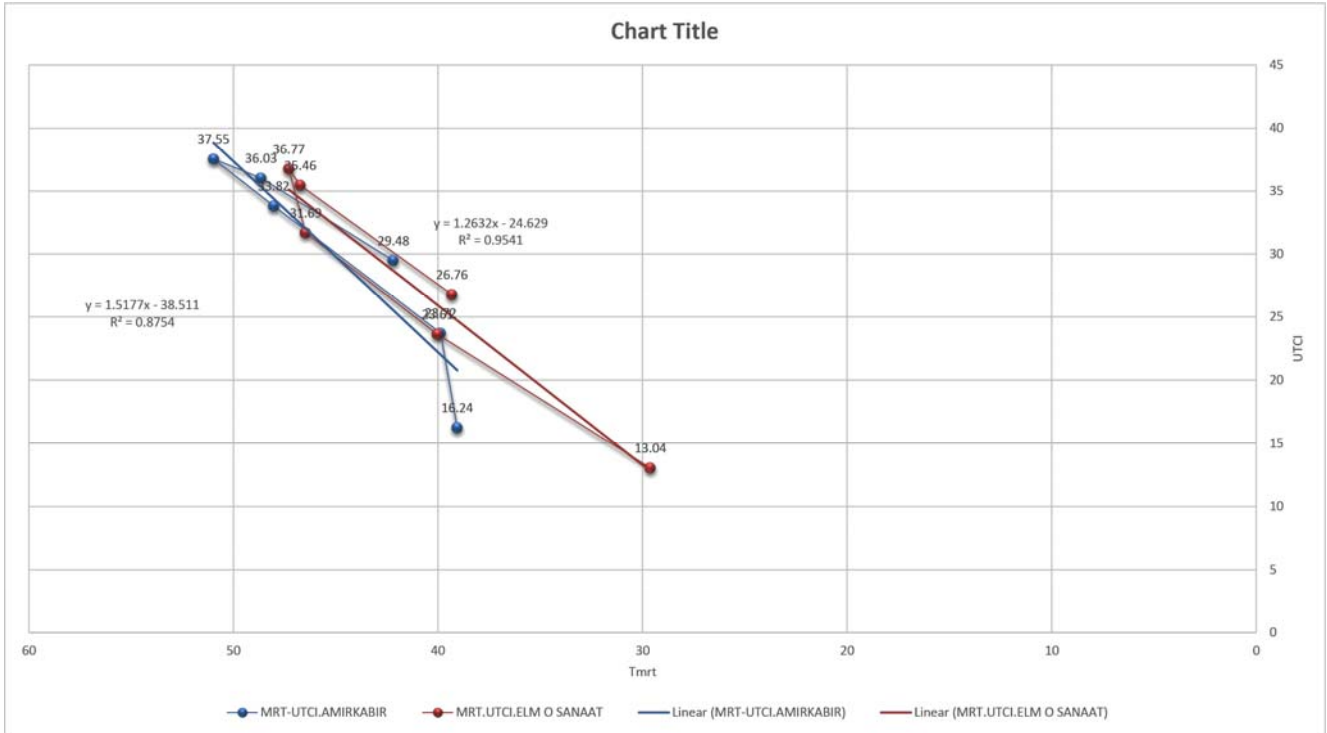


Fig 18. Comparison of correlation UTCI of both campuses.

5. Conclusion

This study focused on two university campuses (campuses of IUST and Amir-Kabir) in Tehran with different levels of shaded open spaces and discussed the shading effect on outdoor thermal comfort and stress. Outdoor thermal comfort in these two universities was investigated by the UTCI thermal index using the UTCI calculator. This study attempted to demonstrate the effect of different shadow pattern, especially in university campuses to enhance the adaptation of thermal behavior of users. The results of this research will contribute to designing adaptive shaded open spaces to the thermal behavior of the users. The authors examined 10 points in each campus (faculty zones) with onsite measured meteorological data over 6 months (spring and summer) of 2015. In this study, Tmrt was investigated through the changing of the SVF value and its effect on the UTCI thermal index. Shading effects (SVF) in campuses causes decreased the mean radiant temperature of 3.68°C Tmrt in the hottest month of the year (July). In an average of 6 months, it is 3.22°C of Tmrt. UTCI index has been analyzed based on Tmrt and the results demonstrate that, on average, the campus of IUST, is 1.28°C cooler than the campus of Amir-Kabir on the UTCI scale and in July.

Consequently, the comparison of the SVF, Tmrt and UTCI thermal index of the both campuses of IUST and Amir-Kabir are summarized in the below list:

1. SVF

The average SVF in Amir-Kabir University is 0.7206 and in IUST 0.3305. Different SVF value of these two universities creates different shadow patterns in the campuses. It means that just 28 % ground of campus of Amir Kabir university are shaded and 67 % ground of IUST is under tree shadows. Consequently, the students have different opportunities to adapt their thermal behavior with their environment

2. Tmrt

In both of these universities, there are points that have more than 50°C of the Tmrt values but the average Tmrt of each month shows that there is 3.68°C difference in the apex of the Tmrt. There is a quite correlation between Tmrt and SVFs.

3. UTCI

In environments with high SVF values, Tmrt is one of the important components of the UTCI index. On average, there is a 1.28°C difference in UTCI between the two campuses and the maximum difference is in September by 2.72°C. UTCI index differences in September and April are higher than other months but similar to the UTCI index, whereby increasing the Tmrt, the UTCI value increases as well.

This study seeks shaded places on the thermal environment with reliable thermal index (UTCI) for open spaces. Correlation of T_{mrt} with the UTCI will guide the planners and designers to forecast and resolve the environmental thermal issues in order to create sustainable and comfortable open spaces in terms of thermal comfort and also by applying environmental greenery, a convenient adaptive approach can be arranged to create thermally comfortable and attractive living environments.

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