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Comparative study of shading effect of built Environment on thermal comfort in two campuses of Tehran

Abstract:

Environmental thermal conditions around us have a significant effect on the efficiency of people who use these open spaces especially on university campuses where many students from different cities spend their most of time. This paper focuses on the comparative study of the effects of the sky view factor (SVF) on mean radiant temperature (Tmrt) and the thermal indices derived from these parameters in two different universities in Tehran: IUST and University of Amir-Kabir. Thermal comfort of these campuses have the different condition due to their different level of shaded open spaces. Physiological equivalent temperature (PET) is calculated via Rayman for thermal comfort assessment in spring and summer 2015. Subsequently, it determined that by decreasing SVF to 0.4, Tmrt will decrease to 3.04°C. These changes of Tmrt effect on PETs reduction. PET comparison in two campuses illustrates that in an average of PET, there is 0.86°C difference between two campuses in the hottest month of the year (July). IUST campus is 1.39°C cooler on the PET scale. In conclusion, increasing shaded spaces by increasing green spaces and trees can create cooler campuses. Integrated design of shaded open spaces with their architectural forms is recommended as a design strategy to the designers to create a responsive environment in terms of thermal comfort. By this means cooler campuses are more prone to be used by students and their activities.

Key words: University campuses, shaded open spaces, thermal comfort, SVF, Tmrt, PET
Introduction:
In urban areas, the micro-scale is dominated by individual buildings, streets, and trees. Urban environmental quality is a complex and spatially variable parameter which is a function of interrelated factors including the urban heat island (UHI), the distribution of greenery, building density and geometry and air quality (Wong et al. 2007; Nichol 2005).

Universities, like cities, have complex activities and operations with potentially significant environmental impacts (Alshuwaikhat 2008). University buildings have considerable local socio-economic impacts, going far beyond the university itself, owing to their scale. This is also because of the number of people using its facilities not only for educational and research purposes but also living (dormitories) and participating in a variety 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 influence the quality and quantity of outdoor activities. Thermal comfort is generally defined as that condition of mind which expresses satisfaction with the thermal environment (e.g. in ISO, 1984). Thermal comfort in the outdoor environment is mainly related to thermo-physiology, i.e. physiology and the heat balance of the human body (Hoppe 2002). 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). Therefore in this study, the effect of SVF on PET 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 (PET) for open 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.

Literature review:
Previous studies demonstrated that lower daytime air temperature (Cool Island) and higher nighttime air temperature (heat island) in urban canyons are the effects of lower SVF on the thermal 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 and 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). López et al(2016) careereed out a study entitled “Solar radiation and day lighting assessment using the Sky-view Factor (SVF) analysis as method to evaluate urban planning densification policies impacts”. This study identifies and proposes simple methods to assess solar radiation, daylighting availability and Sky-View Factor (SVF) modification, in complex urban environment. Numerical methods and 3D simulation software are combined with photo processing methods using digital cameras with special mirrors to project the hemispherical environment onto a circular image. They analyzed the particularities of different urban scenarios considering the effects of urban densification planning strategies on existing buildings, in particular historical protected buildings. (López et al.,2016). Sharmin et al(2016) observed microclimatic conditions in residential, commercial and educational areas in Dhaka city by study entitled “Analysis of microclimatic diversity and outdoor thermal comfort perceptions in the tropical megacity Dhaka, Bangladesh “. Findings of this paper suggest, urban forms that are more variable with irregular plot sizes and building heights, mostly in traditional areas, have positive responses with respect to the synoptic climate, while planned areas with uniform plot sizes and height, shows a tendency to develop daytime urban heat island effect. In this study revealed that urban geometry and the resultant
climatic variables may not be the only, but one of the most important factors for governing the outdoor thermal comfort sensation in a tropical climate. (Sharmin et al., 2016).

There are some few studies in Iran that are related to the outdoor thermal comfort (Tahbaz, 2007; Behzadfar & Momin, 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 were simulated 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. Hereby, 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 Momin (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.

2: Methodology
2.1: Study area:
This study was conducted in Tehran (51° 20' E, 35° 41' N, and altitude =1368m), the capital of Iran with a population of 8 million and with a moderate climate and hot summers. Most important universities in Iran are located in Tehran and every year hundreds of students from all over of Iran come to Tehran to study. Iran University of Science and Technology (Elm o sanat-e- Iran - IUST) is located in the eastern part of Tehran with a campus size of 420000 square meters. The majority of the campus has been covered with trees and green spaces and because of more shaded open spaces, the outdoor thermal conditions of this university have a better condition rather than 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 PET. Using data from twenty years of temperature observations in Tehran, it can be concluded that: from 15 January to 1 March, the thermal 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).

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

2.2: 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). The measurements of the meteorological data were done via Data logger, type: Lutron LM-8000(A Lutron LM 8000 4 in 1 digital anemometer, hygrometer, light meter and thermometer for measuring wind velocity, humidity, light intensity and temperature). This device were validated through many researches (Gutiérrez et al.,2010; Shahidan et al.,2006; Shahidan et al.,2010; Shahidan et al.,2014; Shahidan et al.,2007; Manteghi et al.,2015). Hereby the 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.

Table 2: Average of meteorological data spring and summer seasons (2015) of Tehran.

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 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.

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 the photo by Spatial pyramid software and SVF is derived from the Rayman model software.

As with the University of Amir-Kabir, 10 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.

Fig.3. Study location: IUST from google map (http://maps.google.com/). Spherical photos were taken using a Hero-3 fish eye lens camera and visual categories of photos by Spatial pyramid software and SVF is derived from the Rayman model software.

The Rayman model was used to calculate the physiological equivalent temperature (PET) based on the sky view factor of the campuses (Matazareskis et al., 2007). 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 (PET) by the Rayman. The SPSS software and Excel were used to compare and discuss on the PET, Tmrt, and SVF.

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

2.3: Calculation of PET as thermal comfort index:
The physiological equivalent temperature, PET, is a thermal index derived from the human energy balance. It is well suited to the evaluation of the thermal component of different climates as well as having a detailed physiological basis (Prata-Shimomura et al. 2009).

The PET index is often used in environmental comfort research for analyzing the physiological behavior of users and pedestrians according to environmental conditions (effect of buildings and climate) (Matzarakis et al. 1999). PET as thermal comfort has been used in several studies of outdoor thermal comfort (Thorsoson et al. 2007; Andrade & Alcoforado 2007; Oliveria & Andrade 2007; Johansson 2006; Emmanuel & Johansson 2006) because the PET index has been primarily designed for outdoor use (Spagnolo & Dear RJ 2003). PET can be calculated using free software (RayMan). This software is validated software for urban complex shading (Lin et al. 2006; Gulyas et al. 2006; Matzaraki et al. 2007). Environmental data for the PET calculation that is required in the Rayman model includes air temperature ($T_a$), relative humidity (RH%), wind velocity (v), mean radiant temperature (Tmrt) and vapor pressure (VP) and personal data such as human clothing and activity and local data such as date of year, time and location. Using this process, assessment of PET can be calculated by importing spherical photos (fish-eye photos) of the sky to calculate the short and long wave radiation fluxes. After importing these parameters to the Rayman model, the Tmrt, SVF, PET and other thermal indices represent the software output.

Table 3: Comfort classification of PET (Heidari & Monam, 2013).

Evaluation of PET has been carried out according to the Tehran PET classification in this paper.

Table4: Comfort classification of PET of Tehran (Monam, 2011).

Results and discussion

3.1 Sky view factor (SVF):

3.1.1 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) receiving direct solar radiation and students who are on this campus are more prone to getting radiant heat and they are exposed to thermal stress. This will be discussed further.
Fig. 5. Spherical photo (fish-eye lens) of Amir-Kabir campus. Visual category of spherical photos based on texture and color codes and numerical analyses by Rayman model software.

3.1.2 SVF value in 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.

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

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

3.2: Mean radiant temperature (Tmrt):

3.2.1: Tmrt in 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 Ta, 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°C < Tmrt < 55.4°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.

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

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.

### 3.2.2: Tmrt of 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°C < Tmrt < 54.5°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.

**Fig. 9.** Tmrt value in spring and summer of 2015. (March 21 - September 22) in the campus of IUST.

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.

### 3.2.3: Comparison:

The calculation of an average of 6 months 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 equal meteorological data for the both campuses, these differences in Tmrt value are related to the difference in SVF value.

**Fig. 10.** Tmrt Comparison of two campuses based on the average of Tmrt for each month.
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, we have 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.

**Table 5:** Pearson correlation coefficient of SVF and Tmrt in the campus of Amir-Kabir.

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 a more shaded open spaces in order to the reduction of Tmrt in landscape and urban designing principles to gain a more sustainable environment.

**Table 6:** Pearson correlation coefficient of SVF and Tmrt in the campus of IUST.

### 3.3 University of Amir-Kabir:

#### 3.3.1 Physiological Equivalent Temperature (PET) of campus of Amir-Kabir:

According to the PET comfort classification, comfort conditions on the campus of Amir-Kabir University occur in May and September whereas April experiences cool conditions, June experiences hot conditions and July experiences very hot thermal conditions.

**Fig. 11.** Monthly diagram of PET based on related SVF changes.

Numerical analyses of the 60 points (10 points over 6 months), highlight that just 10 points of 60 are in the comfort condition (all of them are in May and September) and the others (50 out of 60) points are in the discomfort condition.
3.3.2 SVF-PET:

Numerical analyses of SVF and its related PET as shown by the following chart, highlights that the lowest temperature of each month is related to the lowest SVF and also the highest temperature in the PET scale is related to the highest SVF. The maximum difference in the subtraction of the highest and the lowest temperature is in June, of 4.5°C and the minimum difference is in April.

In terms of SVF value on the campus of Ami-Kabir university, 7 of 10 selected points have an SVF value of more than 0.7, which means that there is less opportunity to adapt thermal behavior with shadows to mitigate thermal stress.

**FIG.12.** Monthly analyses of PET Progression based on related SVF value.

3.3.3 Tmrt – PET:

As mentioned above, Tmrt as heat stress indicator and its correlation with SVF has been mentioned before (observed in both campuses). The measured PET has been analyzed numerically. The analysis shows that in all 6 months and across all 60 points, that the highest Tmrt is related to the highest PET. In the following chart, each PET is represented by its Tmrt. In each category that is based on SVF (10-points category), there are 6 PET that is related to the 6 months and 6 Tmrt are related to the 6 months and it shows that highest Tmrt and PET is related to the highest SVF and by decreasing the SVF value, the Tmrt and PET also decrease. According to the following chart, all the points that have the highest SVF value also have the highest Tmrt and in the same way, the same point reaches the highest PET.

**FIG.13.** Numerical analyses of PET with their related Tmrt for each month based on SVF value.

3.4 IUST:

3.4.1 Physiological Equivalent Temperature (PET) of the campus of IUST:

Monthly evaluations of the PET in the campus of IUST are shown according to the PET classification. It highlights that May and September experience comfort conditions and April experiences cool conditions and June's thermal condition is warm. July and August are hot (the thermal conditions of July on the campus of Amir-Kabir was very hot).

**Fig. 14.** Monthly diagram of PET based on related SVF changes.
All 60 points were analyzed statistically and the result shows that 11 points out of 60 are in the comfort condition and the other 49 points are in the discomfort condition and also 11 points out of 60 have more than 40°C in the PET scale (compared to 17 points in University of Amir-Kabir). This means that shaded places are more prone to have more of a comfort condition.

### 3.4.2 SVF-PET:

The campus of IUST (faculty zones) because of a high more shaded open spaces, has a lower SVF value, and numerical analyses of PET based on SVF (10 points) over 6 months highlight that the thermal conditions of this campus are more fixed and PET changes in terms of SVF are very low and the maximum PET is related to the SVF value of 0.633. The PET has rapid changes in this point and before this (in the other 9 points) the PET changes happen gradually. Because of the low SVF value, ground surfaces of this campus have more shadow, and high shaded surfaces make the environment more adapted in terms of thermal behavioral adaption.

**FIG.15.** monthly analyses of PET based on related SVF value.

### 3.4.3 Tmrt – PET:

Tmrt and its related PET, have been analyzed numerically. The results show that in all 6 months and across all 60 points, the highest Tmrt is related to the highest PET. In the following chart, each PET is represented by its Tmrt. In each category that is based on SVF (10 categories), there are 6 PETs that are related to the 6 months and 6 Tmrt values are related to the 6 months and it shows that the highest Tmrt and PET are related to the highest SVF and by decreasing the SVF value, the Tmrt and PET decrease too. The point that has the lowest SVF value reaches the lowest Tmrt and in the same way, the same point reaches the lowest PET.

**FIG.16.** Numerical analyses of PET with their related Tmrt for each month based on SVF value.

### 3.5 Comparison of PET thermal index based on Tmrt and SVF:

The average of the PET index has been evaluated for each month and compared in one graphical diagram. According to the chart, the campus of IUST is 0.86°C cooler than the campus of Amir-Kabir and in July there is 1.39°C difference in PET values. In this diagram we analyzed the mean radiant
temperature again, to demonstrate how changes in $T_{mrt}$ can affect the PET. According to the diagram, maximum differences between $T_{mrt}$ of campuses is in July (6 evaluated months) so as the similarly the maximum difference between PET of campuses is in July. We have evaluated $T_{mrt}$ by the RayMan model. According to the previous sections (correlation of $T_{mrt}$ and SVF), on the campus of Amir-Kabir university with high SVF values, the correlation of $T_{mrt}$ and SVF highlights that in the environment with high sky-view conditions, the thermal comfort condition is strongly affected by the $T_{mrt}$.

In the following diagram, the relationships of the $T_{mrt}$ and PET have been described by a regression coefficient diagram. In Amir-Kabir University, $R^2$ value is 0.9133 and in IUST University, it is 0.945. All of these numbers ($R^2$) represent the high correlation between $T_{mrt}$ and PET that strongly affect human thermal sensation. The differences of $T_{mrt}$ in these two campuses result from the SVF differences and the SVF value of two campuses is related to the greenery.

In addition, $T_{mrt}$ reduction by reducing the SVF value can enhance the user's adaptation thermal behavior by increasing the shaded spaces can make the campuses more adaptive to the users by the integration design of trees, to architectural spaces.

**Conclusion:**

Thermal comfort in the open spaces is a significant parameter in public mentally and physically health. Increased hot days of cities because of the urban heat island is the common phenomenon in cities. This phenomenon effect cites quality by different aspect such air quality, Use of fossil fuels … therefore, cooling strategies in the urban and similar spaces like campuses design is one of the important issues of the designers. 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 PET thermal index using the RayMan model software. 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 PET. 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. PET index have been analyzed based on Tmrt and the results demonstrate that, on average, the campus of IUST, is 0.86°C cooler than the campus of Amir-Kabir on the PET scale and in July there is 1.39°C difference in the evaluation of PET.

In conclusion, increasing shaded spaces by increasing green spaces and trees can create cooler campuses and more to point, integrated design of architectural forms and green spaces decreases the high sky exposed open spaces and by this means, heat stress mitigation is outcome of the low radiated open spaces. Consequently, cooler campuses are more prone to be used by students and their different activities. This study seeks shaded places on the thermal environment with reliable thermal index (PET) for open spaces. Correlation of Tmrt with the PET 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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<td>878.900</td>
<td>6.19</td>
<td>12.05</td>
<td>-4.48</td>
<td>80.294</td>
<td>26.83</td>
</tr>
<tr>
<td>878.200</td>
<td>4.35</td>
<td>10.30</td>
<td>-1.58</td>
<td>92.782</td>
<td>33.74</td>
</tr>
<tr>
<td>875.500</td>
<td>4.35</td>
<td>10.34</td>
<td>0.51</td>
<td>98.132</td>
<td>36.74</td>
</tr>
<tr>
<td>850.100</td>
<td>3.74</td>
<td>10.33</td>
<td>-0.38</td>
<td>95.864</td>
<td>35.48</td>
</tr>
<tr>
<td>881.200</td>
<td>3.9</td>
<td>17.48</td>
<td>2.87</td>
<td>86.622</td>
<td>30.29</td>
</tr>
</tbody>
</table>

Table 4: Analyses of Tehran’s thermal conditions based on ASHREA STANDARD (Heidari, 2009).

<table>
<thead>
<tr>
<th>Thermal sensation</th>
<th>PET (Lin et al., 2010)</th>
<th>PET (Hoppe, 1999) West and center of Asia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very cold</td>
<td>Less than 14</td>
<td>Less than 4</td>
</tr>
<tr>
<td>Cold</td>
<td>14-18</td>
<td>4-8</td>
</tr>
<tr>
<td>Cool</td>
<td>18-22</td>
<td>8-13</td>
</tr>
<tr>
<td>Slightly cool</td>
<td>22-26</td>
<td>13-18</td>
</tr>
<tr>
<td>Comfortable</td>
<td>26-30</td>
<td>18-23</td>
</tr>
<tr>
<td>Slightly warm</td>
<td>30-34</td>
<td>23-29</td>
</tr>
<tr>
<td>Warm</td>
<td>34-38</td>
<td>29-35</td>
</tr>
<tr>
<td>Hot</td>
<td>38-42</td>
<td>35-41</td>
</tr>
<tr>
<td>Very hot</td>
<td>More than 42</td>
<td>More than 41</td>
</tr>
</tbody>
</table>

Table 6: Comfort classification of PET (Heidari & Monam, 2013).
<table>
<thead>
<tr>
<th>PET(°C) Tehran (Monam, 2011)</th>
<th>Thermal Comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 17.5</td>
<td>Cool</td>
</tr>
<tr>
<td>17.5-25.0</td>
<td>Slightly Cool</td>
</tr>
<tr>
<td>26.32</td>
<td>Comfortable</td>
</tr>
<tr>
<td>33-36</td>
<td>Warm</td>
</tr>
<tr>
<td>37-40</td>
<td>Hot</td>
</tr>
<tr>
<td>More than 41</td>
<td>Very hot</td>
</tr>
</tbody>
</table>

Table 4: Comfort classification of PET of Tehran (Monam, 2011).

<table>
<thead>
<tr>
<th>VAR 00001</th>
<th>Apr</th>
<th>may</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Correlation</td>
<td>.991**</td>
<td>.728*</td>
<td>.907**</td>
<td>.812*</td>
<td>.806*</td>
<td>.967**</td>
</tr>
<tr>
<td>SIG (2-tailed)</td>
<td>.000</td>
<td>.017</td>
<td>.000</td>
<td>.004</td>
<td>.005</td>
<td>.002</td>
</tr>
<tr>
<td>N</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 5: Pearson correlation coefficient of SVF and Tmrt in the campus of Amir-Kabir.

<table>
<thead>
<tr>
<th>VAR 00001</th>
<th>Apr</th>
<th>may</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Correlation</td>
<td>.585**</td>
<td>.785*</td>
<td>.811**</td>
<td>.823**</td>
<td>.797**</td>
<td>.825*</td>
</tr>
<tr>
<td>SIG (2-tailed)</td>
<td>.005</td>
<td>.007</td>
<td>.004</td>
<td>.003</td>
<td>.006</td>
<td>.003</td>
</tr>
<tr>
<td>N</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 6: Pearson correlation coefficient of SVF and Tmrt in campus of IUST.
Fig. 1. Metrological data logger (Lutron LM-8000) and Hero3 fish eye lens camera.

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.
Fig. 3. Study location: IUST from google map (http://maps.google.com/). Spherical photos were taken using a Hero-3 fish eye lens camera and visual categories of photos by Spatial pyramid software and SVF is derived from the Rayman model software.

Fig. 4. procedure of investigation of thermal comfort and thermal stress on university campuses based on Tmrt and SVF.
Fig. 5. Spherical photo (fish-eye lens) of Amir-Kabir campus. Visual category of spherical photos based on texture and colour codes and numerical analyses by Rayman model software.

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.

Fig. 8. Tmrt value in the spring and summer of 2015 (March 21-September 22) in campus of Amir-Kabir.
Fig. 9. Tmrt value in spring and summer of 2015 (March 21 - September 22) in campus of IUST

Fig. 10. Tmrt comparison of two campuses based on average of Tmrt for each month.
Fig. 11. Monthly diagram of PET based on related SVF changes.

Fig. 12. Monthly analyses of PET based on related SVF value.
FIG. 13. Numerical analyses of PET with their related Tmrt for each month based on SVF value.

Fig. 14. Monthly diagram of PET based on related SVF changes.
FIG. 15. Monthly analyses of PET based on related SVF value.

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