Role of Environmental Simulation at the Early Stage of Design in Order to Achieve Outdoor Thermal Comfort: a Case Study of *Ekbatan* and *Apadana* Residential Complexes in Tehran, Iran.

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Abstract

Outdoor environment and its requirement are one of the crucial issues of the designer especially in the residential complexes .early stage simulation is a method which is considered in many studies and projects to demonstrate and predict the environmental performance of the buildings. Therefore in this study to assess the importance of the early-stage environmental consideration through simulation method using both simulation tools and experimental measurement of the environmental parameters. Thus Envi-met 4 is used for simulation purposes and data logger (Lutron LM-8000) is used for frequent measurements. In order to show the accuracy of the simulated Tmrt, the measured data are put into the formula of the Tmrt and all of the calculations are done via Grasshopper parametric tool. *Ekbatan* residential complex is more prone to have a comfortable environment in comparison with the *Apadana* residential complex but the best happens in the simulated residential complex. The finding of this study demonstrates that if at the earlystage of the design process, the environmental parameter takesinto consideration, the final real output will be more satisfactory in terms of outdoor thermal comfort.

***Keywords*:** Environment, Thermal comfort, Early Stage simulation, Residential complex

1. Introduction

Mostly, buildings are the key source of the energy consumption and energy consumption variations is basically depends on the environment's thermal condition and it differs from 30%-45% of the total globaldemand (Asimakopoulos et al., 2012; Pout & MacKenzie & Bettle,2002). Therefore lots of studies have been carried out in energy and its related factors to estimateand observe the thermal performances of the buildings in different conditions. To achievethe responsible building in terms of thermal condition and performance objectives, the building geometry, orientation, fenestration configurations, and thermal management strategies must become supporting pieces of the entire-building thermal concept. (Konis et al., 2016). Inactive keys are engineer's tools to meet sustainable environment. Ordered flowtask is required to arrange the optimal application of sustainable strategies. A deficient acquaintance of the operative optimum passive principlesleads the designers to use the active engineering facilities. One of the most important aspects of the comfort sensation of the settlers in the modern residential complexes is the outdoor thermal condition. Level of the life quality in most of the living spaces is the outcome of the interaction of dwellers with their surrounding environment (Das, 2008).In the outdoor setting, thermal comfort condition in residentialcomplexes is affected by individual buildings, streets and trees. outdoor environmental quality is a multifaceted variable which is a function of interconnected factors including the UHI, the greenery level, building density and geometry and air quality(Wong et al,2007; Nichol& Wong,2005). When it comes to building geometry, in the human scale become much more crucial in terms of creating shaded semi-open spaces in connection with its open environment. (Spagnolo& De Dear,2003; Hwang&Lin,2007; Nakano& Tanabe,2004) Generally, the semi-outdoor environments are radiation sheltered space and they are comfortable in terms of annoying radiation and wind velocity (Van Hooff et al.,2010; Lai et al.,2014). Integrated environmental spaces and optimal design process are interested recently by researchers and the designers.Understanding the buildings performances by reliable simulation in an earlier stage of design will ignore the further correction in the construction stage. Passive strategies will force the designer to consider the local climatic features and make the buildings more adaptive to its surrounding environment and according to what was happened in traditional architecture with its whole unique identity of responsibility to its environment. The counterparty architecture suffers from the inefficient knowledge of contextual passive strategies and most of the designers consider anactive solution in thelate stage of the design to get an effective energy based results. Such an awareness about the performance of the building and its effect on

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human sensation requires a cohesive design team-work to study a wide-ranging set of design parameters such as forms, optimum orientation, the albedo and etc. and their effect on the whole building. Therefore the thermal comfort in both outdoor and semi-outdoor spaces to evaluate the thermal characteristic of the buildings at the early stage of design using reliable simulation tools. The result will meet the designer's requirement to have a correct insight into the buildings in the real world. Therefore this paper follows up two main issue and purposes including the emphasising on the necessity of the simulation tools for architectural design processby andasecond issue the reliability of the simulation software especially in terms of Mean Radiant Temperaturebecause of the complexity of calculation Tmrt in an outdoor setting as the main indicator of outdoor heat stress. The validation of Tmrt is crucial in this study to illustrate that outputs of the simulation process areapplicable in the real world.

2. Literature Review

2.1 Outdoor thermal comfort models.

In open spaces, settlers are exposed to surrounding environmental conditions of solar radiation, Shading, and variation of the wind directions and speeds. (Chen& Ng, 2012). Mostly, Measuring of the thermal comforts were done through PMV and PPD thermal index (Chen& Ng, 2012) but recently, the PET(physiological equivalent temperature) thermal index is introduced as a reliable thermal index for outdoor settings.(Lai et al., 2014; Taleghani et al., 2015; Ojaghlou & Khakzand, 2017). A field study paper was conducted at 14 points across 5 countries in Europe, and the findings indicated that more than 75% of people are comfortable on a yearly basis (Nikolopoulou& Lykoudis, 2006). The authentic thermal sensation votes were compared with PET, T-H (Temperature-Humidity) and the wind-chill indexes(Tseliou et al., 2010). Experimental studies were done at outdoor sites in increasing number of cities such as, Japan, Tajimi, Chiayi, Eindhoven and Groningen, Malaysia, Athens and etc.(Knez, I., & Thorsson, 2006; Knez, I., & Thorsson, 2008; Nakayoshi et al., 2015; Lin et al., 2013; Makaremi et al., 2012). Simulating analysis are becoming common methods among researchers and designers (Taleghani et al., 2015; Onomura et al., 2015; Nazarian et al., 2017; Salata et al., 2016; Taleghani et al., 2016).Five different urban forms were analyzed through simulation method via Envi-met freeware by Taleghani et al. In this study, singular East-West, and North-South, linear East-West and North-South, and a courtyard form were analyzed for the hottest day so far in the temperate climate of the Netherlands (19th June 2000 with the maximum 33 °C air temperature). ENVI-met was used for simulating outdoor air temperature, mean radiant temperature, wind speed and relative humidity whereas Rayman was used for converting these data into Physiological Equivalent Temperature (PET). The models with different compactness provided different thermal environments. The results demonstrate that duration of direct sun and mean radiant temperature, which is influenced by urban form, play the most important role in thermal comfort. This paper also shows that the courtyard provides the most comfortable microclimate in the Netherlands in June compared to the other studied urban forms. The results are validated through a field measurement and calibration. (Taleghani et al., 2015). In order to achieve an integrated method and tools for urban environmental problems, were predicted alongside building energy and urban wind flow analyses (CFD simulation) and Standard Effective Temperature (SET). This study demonstrated the critical importance of a comprehensive thermal comfort model that considers the flow field patterns as well as the realistic heating distribution of urban surfaces. It is founded that even in the shaded areas in the street canyon, SET changes up to 10 °C due to the wind sheltering in the urban roughness, furthermore, complex scenarios can be evaluated in order to evaluate the effect of urban design on thermal comfort, and ultimately achieve a climate-conscious design.(Nazarian et al., 2017).Simulation method was used in a study to develop the Outdoor thermal condition of the tourists in historical areas of Isfahan. Iran.In this study along with performing field measurements in the intended historical sites, a questionnaire was used to determine the thermal comfort range of tourists. ENVI-met is used in order to properly simulate the outdoor thermal environment of the historical touristic areas in Isfahan during the hottest as well as the most touristic month of the year. The results of the questionnaire and simulations are compared with each other. It was shown that three historical sites with higher thermal stress experience an unpleasant thermal condition. The results of the questionnaire show that the comfort range of tourists is within 23.06–29.73 °C PET. The thermal conditions of Si-o-Se Pol, Hasht Behesht and Naqsh-e-Jahan are within the thermal comfort range at 19,20 and 21 p.m. respectively. During the daytime, thermal comfort conditions varied from 4.9 °C PET at 8 a.m. to 8.1 °C PET at 3 p.m. Early morning hours were the most comfortable time to visit the historical sites of Menar-e-Jonban, Masjed-e-Jame and Vank Cathedral in Isfahan. During the peak hours of heat, the priority of thermal comfort goes to Masjed-e-Jame, Menar-e-Jonban,and Si-o-Se Pol, respectively (Nasrollahi et al., 2017).

2.2 Outdoor thermal comfort in residential spaces

The outdoor thermal condition has a significant role in increasing the quality of outdoor spaces.(Nikolopoulou& Lykoudis,2006; Thorsson et al.,2004; Santamouris & Kolokotsa, 2015) thermal condition of the open spaces in the residential complexes is key to the public activities(Wilson et al.,2008; Jim& Chen, 2006; Li et al., 2016; Wu et al.,2016). The created micro-climate in the residential complex was quite unknown and many types of research have been carried out in order to increase awareness of the thermal behavior of residential complexes.(Aniello et al.,1995; Faizi et al.,2011; Fuentes-Cortés et al.,2015). In 1995 Aniello et al. have conducted a study using LANDSAT TM satellite data and GIS software to survey the urban heat island in two cities Texas and Dallas and they claimed that urban heat island is intensified in a residential neighborhood because of the scarcity of the green spaces and trees. The awareness of the urban heat island is restricted to the measurement facilities and it is not predictable in the early stages, therefore, the simulation tools were invested and most of the researches have focused intently on the patterns. Lin et al., numerical simulation of the different pattern of the greenery in open spaces using Standard Effective Temperature (SET) in this study different patterns of greenery were examines and they reported a different view of the using trees and. (Lin at al., 2008). Different orientation was analyzed using simulation methods in a study to investigating different urban design scenarios. In this study uses two different thermal indices and examines two different street orientations in summer and winter using microclimatic simulations with ENVI-met and analyzing the thermal comfort maps for the studied cases. Shading is an essential strategy to reduce thermal stress and by using vegetation and shading devices, it is even possible to achieve thermal comfort during the warmest hours in the summer which is the most problematic season in Damascus. The improvement of the Physiologically Equivalent Temperature (PET) between the existing and suggested urban design for the east-west street orientation at 14:00 is about 19 °C and it is reported that efficient use of vegetation and landscape elements positively affects the thermal environment and thus develops the quality of urban design.(Yahia & Johansson,2014). Outdoor thermal condition and its effective factors such as thermal adaptation were scrutinized in a study namely" Outdoor thermal comfort and activities in the urban residential community in a humid subtropical area of China" by Li K et al at 2016. Analysis results confirmed that the thermal experience and expectation existed and changed people's perceptions about the outdoor thermal environment in different seasons. The 90% acceptable physiologically equivalent temperature (PET) range affected by the local climate and thermal adaptation was 18.1–31.1 °C. The residents adapted to the outdoor spaces through adjustment of clothing, activity spaces and activity times in different seasons (Li et al 2016).Climatic effect of the central courtyard in the traditional house of Tabriz. Iran, has been investigated via Envimet 3.1 in terms of outdoor thermal comfort by Moradi et al in 2018 which the results demonstrate that through declining the area of the courtyards and the nearby walls create a much more shaded areas, and decreasing the amount of passive heat storage in the surfaces of courtyards in the cold seasons. This should be mentioned that in this study, the courtyards are investigated through other social factors which are not the matter of the present study (Moradi et al., 2018).

Effect of greenery on thermal comfort in residential environments has been conducted in Wuhan in hot summer and cold winter zone by Li et al. The results of this study demonstrated that the impact of vegetation on both heat environment and ventilation depended on tree arrangement, LAI, crown width, and tree height. The comparison of 3 tree distributions revealed that trees with anART < 2 (as "Aspect ratio of trees", ART) should be a priority to mitigate hot environments due to the large effects on PET reduction in summer. Evergreen species with an ART < 2 also effectively decreased wind speed in winter as well as blocked direct sunlight, resulting in negative effects on PET. Tall trees with a large LAI and canopy diameter should be a priority to improve the comfort of outdoor environments (Li et al, 2017).

2.3 Thermal comfort of semi-outdoor spaces

Thermal comfort of the semi-outdoor spaces are not considered as much as outdoor spaces but in some studies the importance of the semi-outdoor thermal comfort are reported but the number of them is limited (Spagnolo & De Dear, 2003; Nakano & Tanabe, 2004; Hwang & Lin, 2007; Liang et al., 2011). One of the main studies of asemi-outdoor condition which has been conducted by Spagnolo & De Dear in 2003 and in this study,the thermal comfort of 1018 subjects in outdoor and semi-outdoor locations in subtropical Sydney was investigated by a questionnaire and a comprehensive package of micro-meteorological instruments. The findings have demonstrated that the thermal neutrality in terms of the thermal comfort index OUT_SET of 26.2 °C was significantly higher than the indoor SET counterpart of 24°C (Spagnolo & De Dear, 2003). In 2007 a study namely "Thermal comfort requirements for occupants of semi-outdoor and outdoor Environments in Hot-Humid Region." Has been carried out by Hwang & Lin and in this study, an extensive field survey of five public places in Taiwan obtained 8077 sets of data. In this study discussed thermal sensitivity and proposed thermal comfort ranges, neutral temperatures, and preferred temperatures for semi-outdoor and outdoor environments. The results show that occupants of semi-outdoor and outdoor environments are more tolerant regarding thermal comfort than are occupants of indoor environments. Furthermore, global radiation appears to have greater potential to change subject thermal sensation than air movement. In a hothumid region such as Taiwan, semi-outdoor and outdoor environments, applied with sunshine eliminating design strategies, can effectively increase occupant thermal comfort (Hwang& Lin, 2007).Using Pilot spaces in the residential spaced are becoming popular among the architects and its rewarding effects on the thermal sensation of the people in the semi-outdoor and outdoor conditions. Xi et al have conducted a field measurement and using questionnaire method to assess the thermal condition of people in these space. The questionnaire survey showed that 3 SET* values seem to be the inflection point of local acceptance rate to the outdoor thermal environment: 30 °C (inflexion point of 100% and 80%), 32°C (inflection point of 80% and 65%), and 34 °C (inflexion point of 65% and 30%). Both of the SET* index value under piloti and out of piloti area decreased with the increase of piloti ratio. A 100% piloti ratio can highly optimize the local outdoor thermal comfort. For the area out of piloti, the SET* in all area is in the 40 °C limit, and about 50% area is expected to gain 30% acceptance rate (35°C), and about 10% area reach the need of 65% acceptance rate (34°C). For the area under piloti, 100% area meet the need of 30% acceptance rate (35°C), and about 40% area meet the need of 65% acceptance rate (34°C). It is noticed that, when the pilot area is 40%, no area is in the 40°C limit, which should be due to the very low wind velocity under piloti area.(Xi et al.,2017). In another study, Piloti spaces were analyzed through a study via CFD simulation and questionnaire method in China. The results showed that, due to the strict climate, for that area without shading measurement, only the whole space of 100% piloti ratio case meet the need of SET limitation level (less than 40 °C), for other cases, part of the space is controlled with this level. For the space shaded by piloti, the area percentage that SET is in the limited range (less than 40 °C) of 60% piloti ratio case is about 62%, and for 80% and 100% piloti ratio cases, it is 100%. It is noticed that when the piloti ratio is 40%, the thermal comfort of space shaded by piloti is very strict, which should be due to the low wind velocity. A 100 percent piloti ratio can highly improve the outdoor thermal comfort, and 100% area space meet the need of 30% acceptance rate (35°C), and about 40% area meet the need of 65% acceptance rate (34°C)(Xi et al.,2017).

2.4 Thermal consideration in the early stage of design

Ochoa and et al. advised a parametric tool to stimulate the energy consumptions and the visual comfort in 2009.This paper has presented New Facades, a model that helps pass from ideas to significant concepts in the design of intelligent facades. It has used energy and visual comfort strategies abstracted from a prescriptive energy code for hot climates to suggest a range of good starting solutions. Designers can have energy and visual comfort estimations to these alternatives through an advanced stage energy simulation program such as Energy Plus, or explore them further with other tools. In 2009, a study has been done by Schlueter & Thesseling to assess building information model for energy and energy purposes in the early stage of design. Their findings describe o different models to evaluate the performance of the building in its later stages especially in the aspect of energy and exergy. Early stage consideration of the environmental issues is considered in some studies through last decade. Attia and et al., in 2012 carried out a study namely "Simulation-based decision support tool for early stages of zero-energy building design" to show energy simulation software as a means of developing a decision support tool allows designers to rapidly and flexibly assess the thermal comfort and energy performance of early design alternatives. An integrated design approach was advised by Granadeiro et al., in 2013. Results of this study illustrate that both geometry and energy performance influence building shape design decisions. They proposed a solution to integrate energy simulation in design systems and methodology was created and applied to an existing shape grammar design system. Building shape design alternatives were shown, with different energy demand values and finally, they claim the energy performance data is crucial to decide between the designs alternatives. Negendahl in 2015 has done a review study namely "Building performance simulation in the early design stage: An introduction to integrated dynamic models" to conclude the previous processes in 5 highlights:

1-Current early design methods of building performance simulation integration are reviewed.

2- Current methods supporting simulation feedback for various users are reviewed.

3- Best building performance is ensured when experts are collaborating in design teams.

4- Integrated dynamic models may provide most customized performance feedbacks.

5- Integrated dynamic models may provide the most flexibility while maintaining validity.

Finally, the study proposed an in the comprehensive process comprises 3 steps:

1- Modeling geometry

2-Modeling data

3- Modeling calculation

Oliveira and et al in 2016 carried out study namely "Out with domain...within terrain - Effects of early design energy modeling on architects' design practice". The findings of this study indicated differing organizational, team and project approaches with an emphasis placed on legitimating established design assumptions across the three firms. The implications of the findings are twofold. First, the analysis provides an initial overview of how early stage design energy modeling is considered in design in architectural practice in the UK. Second, the paper provides an understanding of how architects negotiate to mean on energy in design. There are also implications for energy policy development in the context of the built environment particularly concerning building performance. A dynamic process of simulation is used for energy efficient building purposes using Energy plus software by Miyamoto and et al., in 2016. In this study, different sketches were examined in order of energy consumptions and finally, they showed the performance of the assumed sketches by visual analysis. Samuelson et al. conducted a study to assess the energy performance of the high rise building in the urban context via parametric tools in 2016. This paper also investigated the effect of urban context as a source of sun shading and found it to have a substantial impact on the design optimization. Ignoring urban context in energy simulation, a common practice, would mislead designers in some cases and result in sub-optimal design decisions. Since in generalized guidelines the future building site is unknown, in this study a method is tested for generating urban contexts based on the floor area ratio and maximum building heights of an urban district. Konis et al., in 2016. Results have shown that the PPOF can deliver between a 4% and 17% reduction in Energy Use Intensity (EUI) while simultaneously improving daylighting performance by between 27% and 65% depending on the local site and climatic conditions. The PPOF and simulation-based workflow help to make generative modeling, informed by powerful energy and lighting simulation engines, more accessible to designers working on regular projects and schedules to create high-performance buildings.

2.5 The computational simulation

Simulation method was advanced to designers to predict their sketches and ideas avoiding further drawbacks (Bulmer, 2001; Christensen & Walters, 2004).The last approach is on the basis of computational simulation using the software. The general procedure is to input the environmental parameters as well as trees, building, cloud cover etc. Consequently, the software will approximate the thermal condition of the study area introducing in the preferred thermal index (Goshayeshi et al., 2013). Increasing number of environmental factors are actually required sophisticated calculation. Matzarakis et al. at 2007 introduced a freeware namely "Rayman" to calculate the Mean radiant temperature (Tmrt) as the main indicator of heat stress. Sky view factor (SVF) can be calculated through o simple fish-eye photo and furthermore three main thermal indexes including SET, PET, and PMV. (Matzarakis et al. at 2007).

It has been used in many studies and the accuracy of its output was proven (Lin & Matzarakis, 2008;Lin et al., 2010; Hwang et al, 2011; Matzarakis et al., 2016). ParaGen has been used by Turrin *et al* to scrutinize the passive thermal control of the sheltered environment in semi-outdoor setting(Turrin et al., 2012). Furthermore, some other software were introduced in order to predicate the outdoor and semi-outdoor conditions including Envi-met (Bruse & Fleer, 1998); SOLWEING (Lindberg et al., 2008) and Town Scope (Teller et al., 2001).

3. Methodology

Parametric design process used to assess the building performance at an earlier stage based on the simulation method.Envi-met3.1 parametric tools can help designers to use the optimal rudimentary building different data (e.g massing, building optimum orientation, optimum height, material albedo, greenery etc.). All of this factors need their own scenario that these scenarios should be completed to the operation and run the simulation via Envi-met 4 and the results compared with the real measured data in the two different residential complexes namely *Ekbatan* and *Apadana* in Tehran. Iran using Data-logger (Lutron LM-8000) to show the role of the early stage of the simulation in the later performance of the outdoor setting of the residential complex. Integrated comparison of the environmental data is done by Excel software and the correlation factors are calculated through the SPSS software. This study has four different parts according to the below list:

1- A theoretical review of the study and the explaining of various aspects of the research.

2- Measuring the environmental parameters with field measurement approach

3- Simulation of desire model with a computational simulation method

4- Validation process with analytical software.

This study is developmental research which research mythology consists of four categories including library-based study, experimental study, Analytical-descriptive research method, and simulation-based research method. The results and outputs were analyzed with inductive manner. At first step of this study different aspect of research is clarified and the related concepts to the topic are explained. The second step of this study is a field measurement via Lutron LM-8000 tool at the level of 1.4 meters of height (according to the height of receptors at simulation step). At third step 4 receptors will be located at 1.4 level of height in the simulation models. The measured environmental parameters are simulated via Envi-met4 freeware. The fourth step of the study has two main subcategories including calculating mean radiant temperature via Grasshopper parametric tool for the selected residential complexes. As second subcategory the calculated mean radiant temperature should be validated via SPSS analytical software to show the applicability of the outputs of the simulated data.

3.1 Envi-met4

The ENVI-met4 urban microclimate was selected to simulate the atmospheric parameters (Envi-met.com, 2016). This software is the 3D microclimate based model that can evaluate the several aspects of the urban canyon, vegetation, materials albedo and… on outdoor thermal comfort and urban heat island mitigation (Bruse & Fleer, 1998).ENVI-met is freeware software that recently has been used by researchers to simulate the effect of the urban vegetation on microclimate (Ali-Toudert, 2007; Chen & Wong, 2006; Peng et al., 2013; Salataet al., 2016). The software runs on a standard x86 personal computer running Windows XP or Vista and does -at the moment - not take advantage of more than one processor or distributed computing. Therefore the maximum number of grid cells is quite limited and it is not possible to simulate the micro-climate of whole cities but only single quarters within. ENVI-met uses a uniform mesh with a maximum of about 300x300x35 cells with the horizontal extension ranging between 0.5-10m and a typical vertical height of 1-5m.(Huttner et al.,2008). ENVI-met carries out the detailed calculation in regards to shortwave and long-wave radiation fluxes with respect to shading, reflection, and reradiation from building systems and the vegetation, and it considers the evapotranspiration and sensible heat flux from the vegetation into the air, including full simulation of all physical plant parameters. ENVI-met has a typical spatial resolution from 0.5m to 10m, and a temporal resolution of 10 seconds. A simulation should typically be carried out for at least 6 hours, but a 24 hours period is more usual. The optimal time to start a simulation is at night or sunrise so that the simulation can follow the solar radiation daily increase. ENVI-met requires an area input file with the 3-dimensional geometry, and a configuration file with the initialization input parameters. (Akbari et al., 2015). The input parameter for vegetation in the ENVI-met model is that of leaf area density (LAD) (m2 m-3) and consists of 10 LAD values for each plant. The LAD values are in turn retrieved from a leaf area index (LAI). The physiological properties of the plants in ENVI-met characterize parameters such as moisture absorption by roots, stomatal resistance, and albedo of leaves (Huttner&Bruse, 2009).

4. Area Study

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.

The *Ekbatan* residential complex is located in the most western part of Tehran with a lush greenery environment. The majority of the outdoor spaces of *Ekbatan* is covered with trees and green spaces and because of more shaded open spaces, the outdoor thermal conditions of this residential complex has a better condition rather than its surrounding urban context.The Apada residential complex is also one of the important residential complexes of Tehran, but the outdoor spaces of this residential complex do not have as much shaded open spaces, so it can be compared with Ekbaran in terms of outdoor thermal comfort conditions, and its related parameters like Tmrt and other environmental parameters. 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 to 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.

Table 1
Analyses of Tehran’s thermal conditions based on ASHRAE STANDARD

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

4.1 Ekbatan residential complex

The *Ekbatan* residential complex is the biggest and the most modern residential complex of Iran including 3 phases. It is located in the most western part of Tehran and it has 5.94 square meter area with 44.981 population. The specific feature of this residential complex is the high level of green spaces in the outdoor setting of the residential complex.

Fig. 1. Aerial map and outdoor environment of the *Ekbatan* residential complex

4.2 Apadana residential complex

The *Apadana* residential complex is also located in the most western of Tehran next to the *Ekbatan* residential complex. On the contrary of the outdoor environment of the Ekbaran residential complex, the open spaces of the *Apadana* residential complex are allocated to the Parking lot and a less suitable area is considered for the pedestrians and public activities. Therefore these two residential complexes deserve to compare in terms of outdoor thermal comfort.

Fig. 2. outdoor environment of the *Apadana* residential complex

5. Discuss

In order to assess the importance of the earlier simulation of the buildings and related environment, the Envi-met4 freeware has been chosen to achieve this task. The *Ekbatan* residential complex is the most important residential complex of the western part of Tehran. Therefore, step by step, the effect of albedo, height, semi-open spaces will be simulated and compared with the thermal condition of the *Ekbatan*.It is a routine method that the hottest day of the yearis chosen of the simulation of the outdoor thermal comfort and the cold days are not considered because the outdoor environment is not useable at cold days. Accordingly, August is the warmest month of the year based in the table1 and the hottest day is chosen for simulation purpose. Thus, the Sunday, August 6 of 2017 were chosen to be simulated and measured the environmental parameters. Table 2 shows the input parameters of the Envi-met4 simulation.

Table 2
Configuration data for ENVI-met4 simulation

Simulation parameters	Simulation inputs
Simulation day	06.08.2015
Simulation period	24h(21:00-21:00)
Spatial resolution	1m horizontally,2m vertically
Initial Temperature	295.15
Wind speed	3m/s
Wind direction (N=0,E=90)	270
Relative humidity(in 2m)	73.27%
Indoor temperature	300K(27°C)
Initial Temperature Upper Layer (0-20 cm)	295.15
Initial Temperature Middle Layer (20-50 cm)	292.15
Initial Temperature Deep Layer (below 50 cm)	289.45
Relative Humidity Upper Layer (0-20 cm)	73.27%
Relative Humidity Middle Layer (20-50 cm)	68.59%
Relative Humidity Deep Layer (below 50 cm)	63.25%
adjustment factor for solar radiation	1
clouds	Default
Turbulence model	Use default values
LBC	For Ta,RH:Open,turbulence;forced

four receptors were distributed through the environment of the proposed residential complex. receptor 2 is located in the semi-opened space.

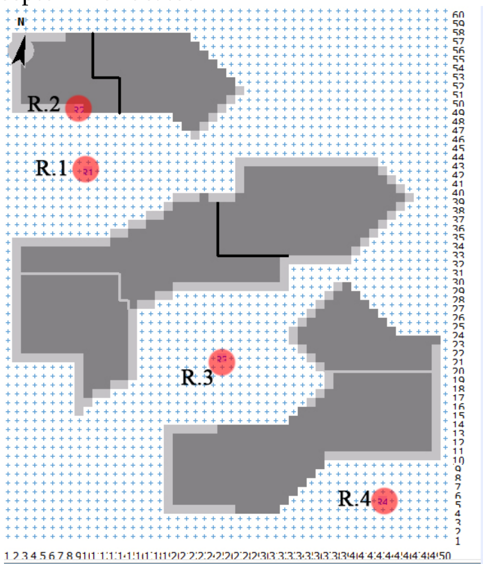

Fig. 3. Location of Envi-met receptors.

The albedo of material is considered 0.3 (a material like a brick) due to lots of studies that have recommended the 0.3(a material like a brick) as suitable materials. therefore as a first step, the Airtemperatures of the measured and simulated models will be analyzed.

5.1 Air temperature

the temperature of the four receptors and the tow selected residential complexes are compared in Figure 4.

Among the Envi-met's receptors, the R1 and R2 have the lowest values but in general, there are no significant differences between the receptors but between allmodels, the *Apadana* residential complex has the highest temperature. Although, as mentioned before, the differences are not considerable and the measured and simulated data are in steady ranges. Thus, it is concluded that if the façade material were chosen like brick material in the selected residential complexes, the Ta would be 1.07 K lower (in average) in the Ekbaten residential complex and 1.37K lower (in average) in the *Apadana* residential complex. Therefore it is illustrated that better materials could be selected if the elaboration was carried out (a material like a brick instead of brutal concrete).

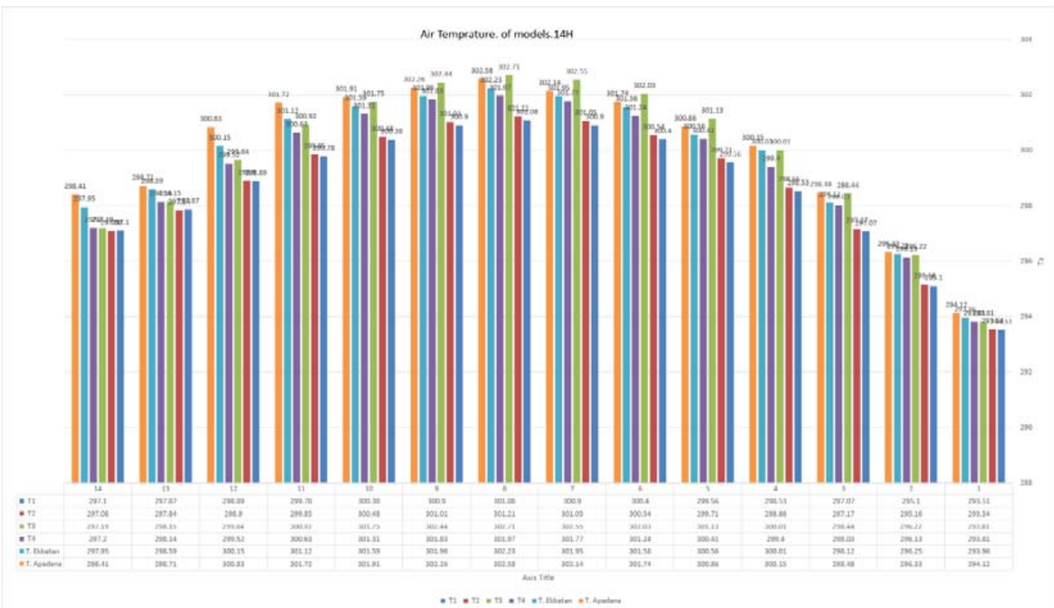

Fig. 4. Comparison of the Air temperatures of the models through 14 hours.

5.2 Relative Humidity:

As a next parameter relative humidity are measured and compared with the simulated data. According to the results, the *Apadana* has the lowest one. Relative humidity is the percentage of the pressure of vapor to the equipoise vapor pressure of water at an assumed Ta. Relative humidity depends on Ta and the pressure of the system of interest. It needs less vapor to achieve more relative humidity at low Ta and vice versa. Therefore in a steady Ta, the moisture of the air is an effective factor. Less greenery and less shaded open spaces, make the local environment to experience the lower Relative humidity in comparison with the surrounding environment. In the Envi-met simulated model, through three steps simulation 20%, 40% and 60 % of greenery are examined and the 60 % greenery is selected for final simulation due to its optimal wind speed and Tmrt values. The open space of the *Ekbatan* residential complex has been analyzed according to greenery texture and color codes and the results show that 56% of the open spaces in the Block A of the *Ekbatan* residential complex are covered by greenery. The results also demonstrate that relative humidity of the Envimet models and the *Ekbatan* are approximately equal. On the other hand, according tothe discussion in the previous step, the *Apadana*'s open spaces have a dramatically low Relative humidity. Therefore, simulation at the earlier stage of designing can make a prediction of how the environment would be like *Ekbatan* or *Apadana*. Thus, it is concluded that if 60% of green spaces would be selected in the Ekbaten residential complex, the RH would be 1.33% higher than existing amount and in the *Apadana* residential complex 32.8% higher than existing amount. Therefore it is shown that simulation at earlier stages of architectural design was carried out the Relative humidity of both residential complexes would be more desirable in terms of outdoor thermal comfort.

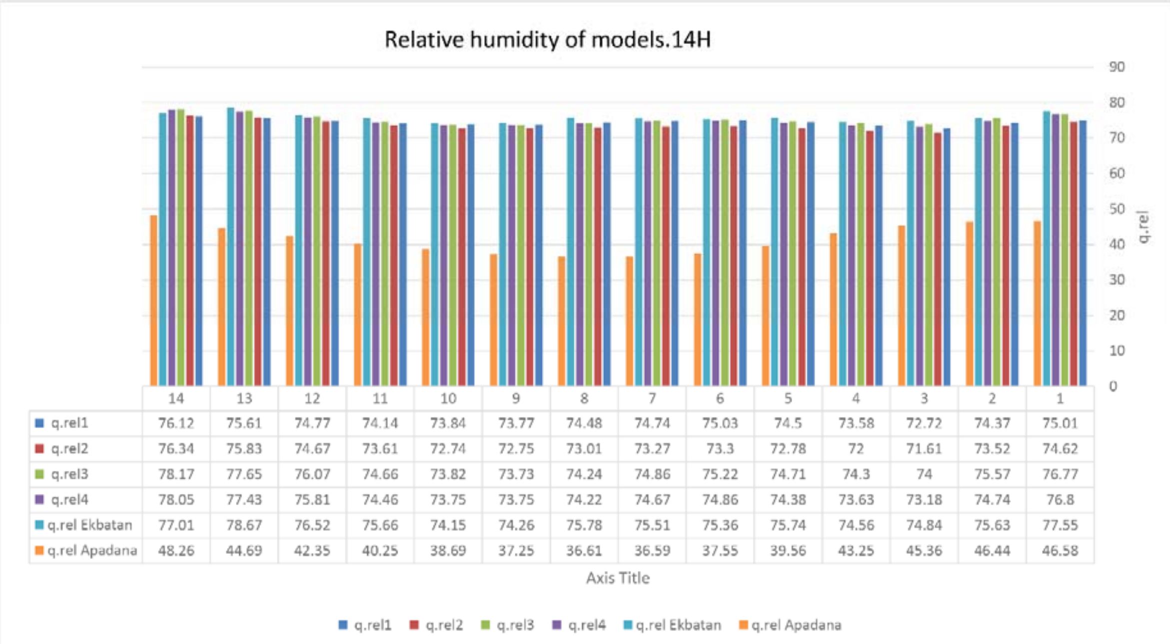

Fig. 5.Comparison of the Relative humidity of the models through 14 hours

5.3 Wind Speed

As a next step, the wind velocity was examined in these three cases. In order to show the importance of the earlier stage simulation, especially for the environmental parameters, all of the three cases were compared in the integrated diagram.

According to the Fig6, it is obvious that the wind speed of *Apadana* residential complex is the highest among all models. Annoying high ventilation of the Apadand is because of the low level of greenery in the environment. But in the other models (both simulated and the *Ekbatan*) the ventilation occurrences, happen in a much more controlled condition through the green spaces. In the models, where ever the level of greenery has changed, the wind speed has changed correspondingly. More greenery causes more controlled ventilation. But the uncontrolled environment will contribute the heat stress or cold stress. Therefore the environmental assessment and thermal requirement of the environment require the awareness in advance. Two different thermal conditions illustrate that the simulation at the earlier stages contribute the accurate awareness of the environment to predict what would happen if the level of the environmental components doesn't apply correctly. Accordingly, the WS of *Ekbatan* residential complex is 0.3 m/s from desire amount and in the *Apadana* residential complexes is 2.08 m/s from desire amount of Wind Speed. Therefore, based on the results, if the simulation were carried out at the earlier stages of design the wind speed of the residential complexes would be closer to the desired amount.

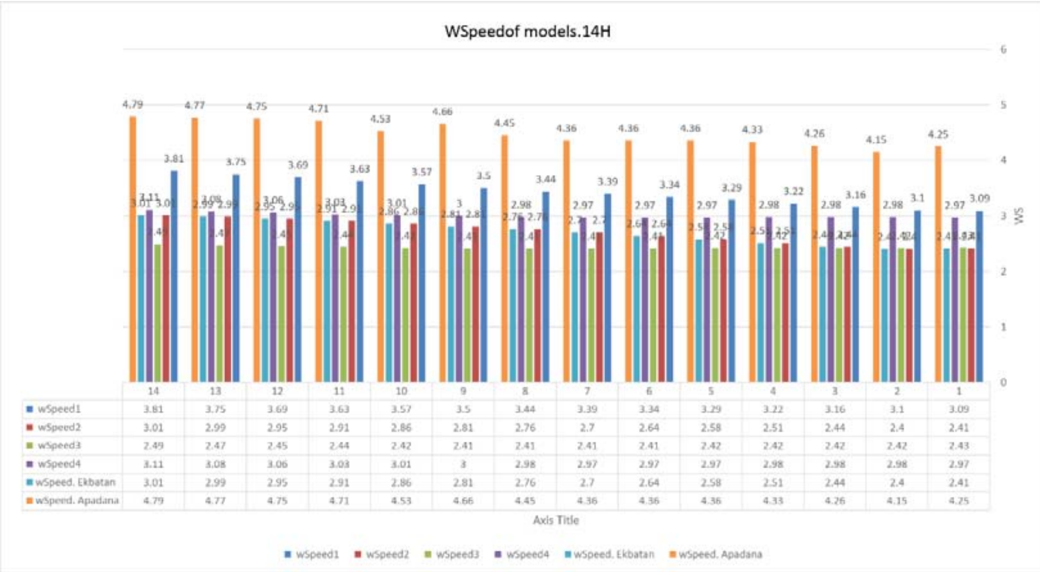

Fig.6. Comparison of the Wind Speed of the models through 14 hours

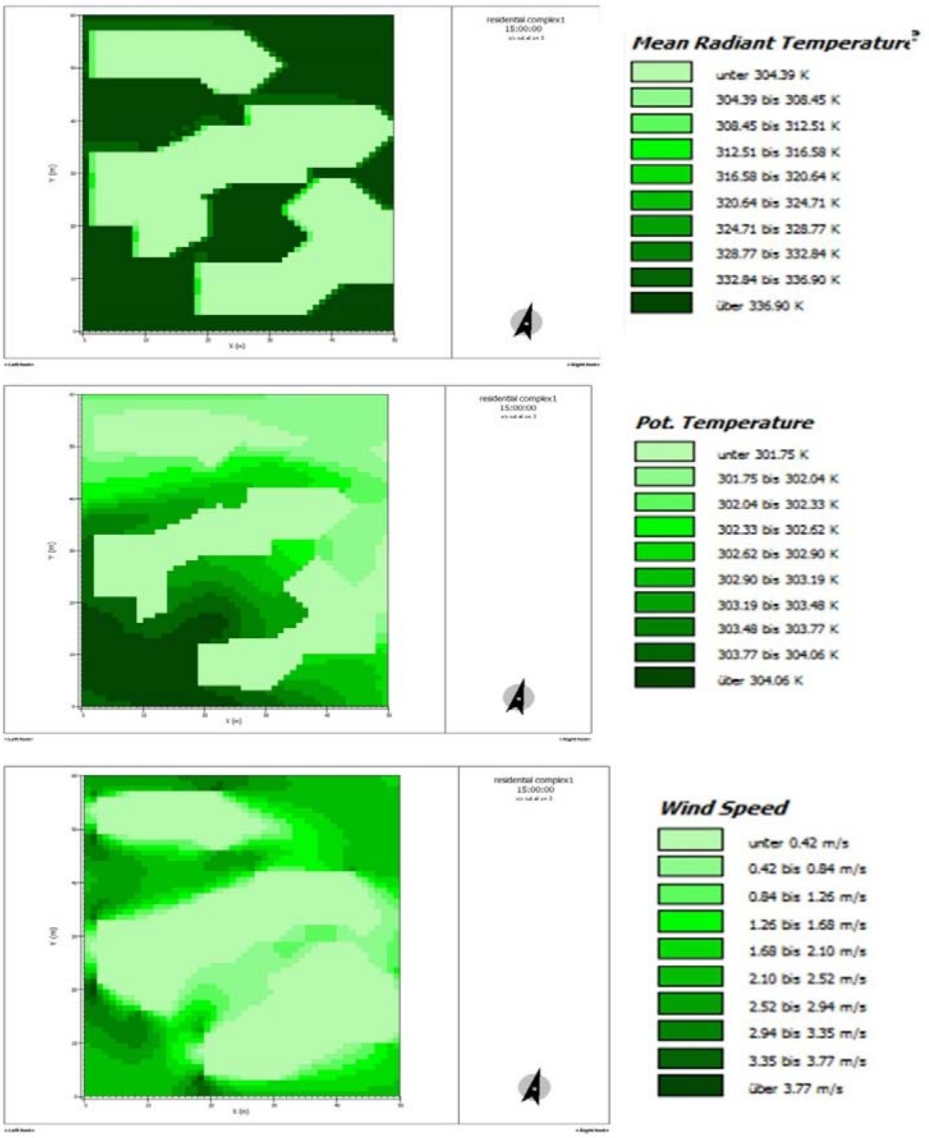

Fig. 7. visual situation of the simulated models at 15:00

5.4 Mean radiant temperature

5.4.1 Calculation the Tmrt via manual calculation

Asa final step, the most important factor of the heat stress namely Tmrt is assessed in these three models. The mean radiant temperature is derived from Envi-met for the simulated models. But for the real cases (*Ekbatan* and Apada residential complexes) the Tmrt is calculated via the same formula which is used in the Envi-met. Based on the formula of the Tmrt, the mean radiant temperature is defined as the combination different environmental parameters including air temperature, globe temperature, and wind speed, Therefore, the validation of mean radiant temperature leads to other values being valid and applicable. The validation process for Tmrt is necessary for the application of the outputs of the simulation tools. Thus, the validation of the simulation software as a second issue and purpose of this study would be carried out in this section. Accordingly, the Tmrt is defined as below formula:

$$Tmrt = \left[(GT + 273.14^4 + \frac{1.1 * 10^8 Va^{0.6}}{* D^{0.4}} * (Tg - Ta)\right]^{1/4} - 273.15$$

Where
Tmrt is the mean radiant temperature (C),

GT is the globe temperature (C),
Vais the air velocity near the globe (m/s),

is the emissivity of the globe which normally is assumed 0.95,
D is the diameter of the globe (m) which typically is 150m m, and
Ta is the air temperature (C).
In the mentioned formula there is needed the for the Globe temperature, therefore in the both residential, the Globe temperatures were measured through 14 hours. The Tg is measured by Globe temperature thermometer which the digital thermometer located in the center of the 15 cm copper globe with a 0.4 thickness
The measured Ta and Tg for both residential complexes is compared in the below table3.

Table 3
comparison of the measured Ta and Tg of the both residential

Ta. *Ekbatan*	293.96	296.25	298.12	300.01	300.56	301.56	301.95	302.23	301.96	301.59	301.12	300.15	298.59	297.95
Tg. *Ekbatan*	295.23	298.64	299.88	301.98	302.25	303.86	303.98	304.15	303.56	303.44	303.66	301.95	299.75	299.25
Ta. *Apadana*	294.12	296.33	298.48	300.15	300.86	301.74	302.14	302.58	302.26	301.91	301.72	300.83	298.71	298.41
Tg. *Apadana*	296.95	298.95	301.66	304.85	305.98	307.88	309.98	310.25	309.88	308.26	305.88	304.25	302.25	300.15

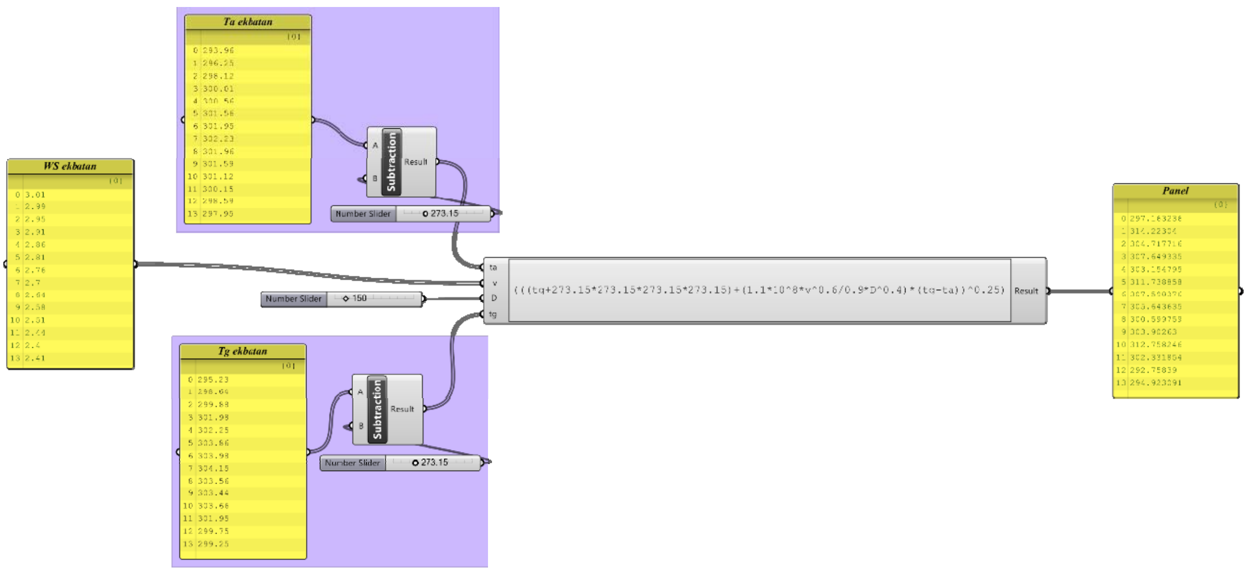

Fig. 8. Calculation process of Tmrt of the *Ekbatan* residential complex in the Grasshopper canvas

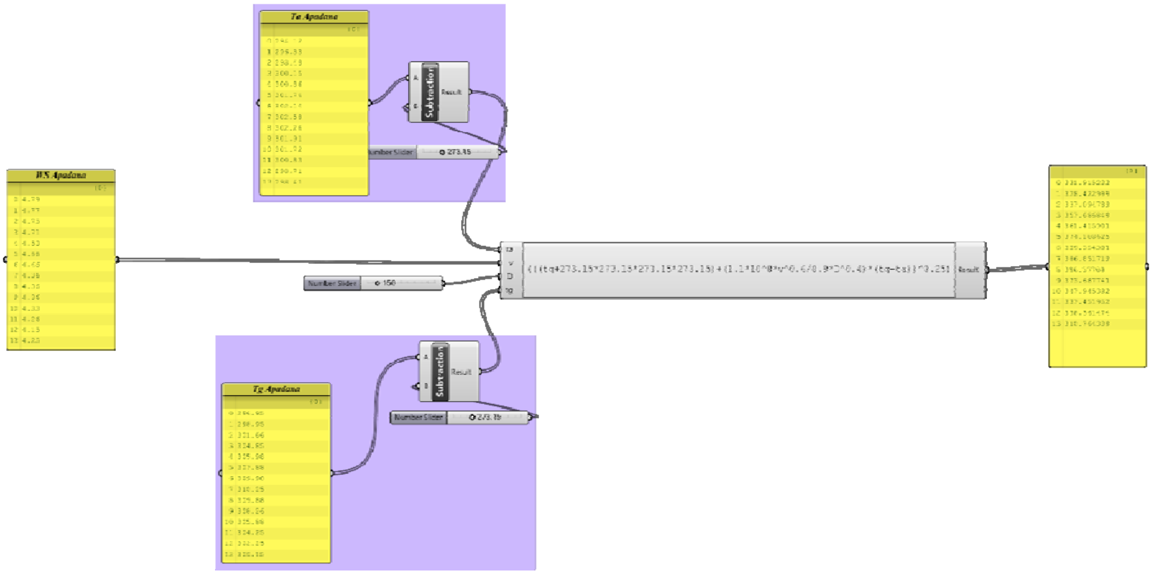

Fig. 9. calculation process of Tmrt of the *Apadana* residential complex in the Grasshopper canvas

The calculated Tmrts are compared with the Envi-met outputs for the models and their correlation are calculated via Pearson correlation value through the measured and simulated hours. The results illustrate there are more 60%(in average) correlation between Tmrt of the All 4 receptors and the measured and calculated Tmrt in both residential complexes.

Table 4
Pearson correlation value between the calculated Tmrt and simulated Tmrt.

	R1	R2	R3	R4
pearson *Ekbatan*	0.700047	0.662941	0.659358	0.653426
pearson *Apadana*	0.62678	0.525004	0.657755	0.614967

5.4.2 Comparison of the Tmrt between the model and the residential complexes.

According to the fig 10, the Tmrt of the *Apadana* has been lowest values and in the all hours of the day is higher than Tmrt of all models.

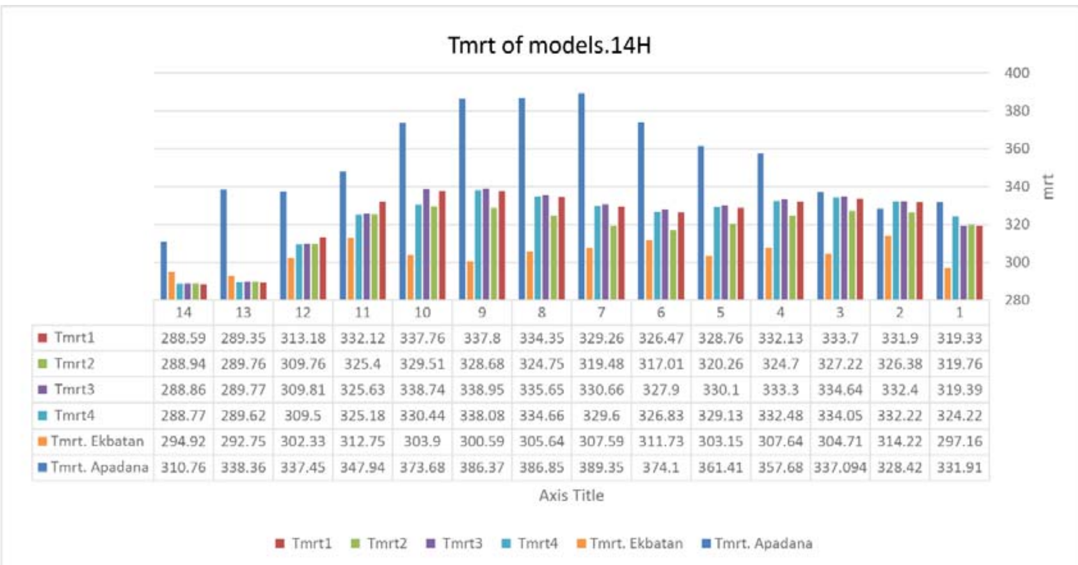

Fig. 10. Comparison of the Tmrt between the models.

Tmrt as the main indicator of the heat stresses, in the *Apadana* residential complexes, creates a more stressful environmental rather than the other models. While the *Ekbatan* has a lower Tmrt than all receptors but it has a similar environment to the data of the receptors in terms of the Tmrt values. Accordingly,Tmrt is the total amount of direct and diffuse radiation on a specific point, therefore, greenery creates a less exposed environment to both total and diffuse radiation, that's why the *Apadana* residential complex has a more radiated environment. The results show that that the differences between the air temperature and the globe temperature are getting increasingly higher amount through solar radiation and they are still high until the sunset. Higher Tmrt through the day hours makes the environment has more stressful hours until the sunset`s hours. The results of this illustrate that is simulation tools were used at the earlier stage of design the tmrt of *Ekbatan* residential complex, 13.75 K would be lower than existing amount and Tmrt of *Ekbatan* residential complex 36.41K would be lower than existing amount.

6. Conclusion

Outdoor thermal comfort is a key factor in the assessment of the Environmental comfort. There are many public spaces which are impossible being in use of pedestrians. The early stage consideration is recommended to minimize the environmental issues. Reliable simulation is the best ways of the early stage consideration to enhance the awareness of the buildings and their surrounding environment performances. Therefore, with proving the reliability of the simulation results, the importance of the early stage consideration will become clearer. in this study three different model including the outdoor environment of the *Ekbatan* residential complex, the *Apadana* residential complex and assumed residential complex were compared integrally to show reliability and importance of the simulation which most of the existing environmental problem would be avoided if the early stage consideration were done. Envi-met4's environmental parameters were compared with the measured data the results demonstrated that the *Ekbatan* residential complex has a better condition in terms of outdoor thermal parameters and the correlation of the measured and the simulated data illustrate that the measured data would be better if the early stage simulation has been taken into consideration. The mean radiant temperature as the main indicator of the heat stress was compared deeply in order to achieve reliable results of the simulation to advice general recommendation to use Envi-met in any design of residential complex in Tehran and any climate like Tehran.

measured data have been put into the formula of the Tmrt and all of the calculation was done by grasshopper parametric tool and the results of the comparison have shown that for the environmental issued Envi-met can be accurate software to be used in the earlier stage of any environmental design in Tehran and any similar climate. Other parametric softer and other environmental issue and the irrelated role at the early stage of design is recommended to be assessed in future studies.

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