CREATING SIMULATION AND ANALYZING SYSTEMS OF THE AMOUNT OF SOLAR ENERGY THAT RECEIVED AT RESIDENTIAL BUILDINGS (CASE STUDY: RESIDENTIAL COMPLEX OF KARAJ MEHRSHAHR)

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ABSTRACT

The quality of a residential complex is based on numerous factors such as their access, privacy, legibility, appearance. Arrangement of the building blocks and their influence on each other are also important parameters for evaluating the large residential design project .

On the other hand, an important criterion for sustainable design is to take advantage of sustainable energies. Considering the disadvantages of high rate of energy consumption in Iran, the more absorption of sunlight energy in winter can cause the more reduction in fuel consumption in cold and mountainous city of Iran which is the case study of this research.

This paper will try to design and implement appropriate computer program method for Simulation and analysis of direct solar radiation received by the windows of residential units in different seasons. This method would be helpful to evaluate different alternatives in designs from the point of utilization of solar energy.

Firstly, we are going to investigate the effective parameters on the amount of solar energy absorbed through the windows in different times of a year and then develop an appropriate algorithm and computer program for simulation the model.

Finally, this algorithm will be used as a parametric analyser in a real project. The project is designing the arrangement of building's blocks in a complex of 500 units in Mehrshar,Karaj.

The result of this paper would be providing a computer program that can be used for simulating the architectural forms and analysing effective parameters in absorption of solar energy.

INTRODUCTION

During recent decades, computer has been more and more used as a powerful tool for designing. It also has had an important role in designing and fabrication process in so many scientific and industrial activities. With applying computer programs, designers can build their designs virtually and evaluate the whole factors before real construction. (Golabchi et al. 2011).

The goal of this research is to use computer as an analyser and simulator tool, which is more engaged in designing process and can be used as a tool for producing optimization in designs.

LITRTURE REVIEW

With the rapid advances of technology, engineers and architects are relying increasingly on building energy simulation to integrate energy efficient system in building design. (Ward, 1975; Lund, 1985; Jensen, 1994; Loutzenhiser, 2006).

There are a few studies about the microclimate and thermal comfort effect of construction on urban areas. (Johansson, 2005;Gulyas, 2006).

They used different computer programs for evaluating solar performance of buildings. Toudert et al. (2005) used Envi-met program to examine the microclimate condition of urban environment.

Gulyas utilized Ray Man model to analyse outdoor thermal comfort condition of complex urban environment.

Hwang et al. (2010) also applied the RayMan model for studying the effects of shading on thermal condition of urban streets in different seasons.

In this study, we developed a method that can predict the amount of direct solar energy received by residential units. What distinguishes this methodoloy from the others are:

1. This method has practical values. It has been designed and implemented for a specific case study, although it can be generalized for other projects as well.
2. In contrary with the other current computer programs, this method doesn't need any special training courses or other computer special expertise. Indeed it can be easily handled by architects. For example this algorithm works in Rhino; which is an architecture modelling software itself; without any problem in transmitting data between these two different programs.

CASE STUDY

The subject of the project in which the simulation has been used is designing a residential township with 6000 residential units in MehrShahr-Karaj, the farthest south zone of Karaj City. Karaj is the centre of Alborz province near to Tehran. Its climate is dry and cold with cold winters and mild summers. (Figure 1)

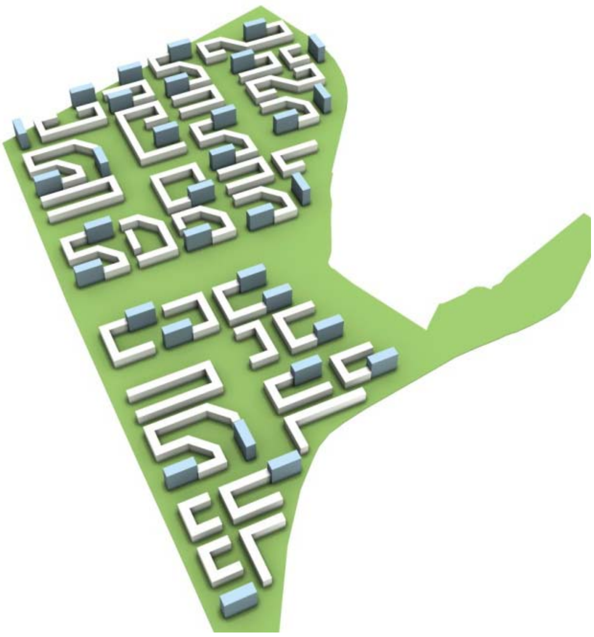


Figure1 General view of residential complex

Shadowing of the adjacent blocks on each other is a negative parameter in energy saving issues in the city of case study. Because heating the building during the winter is more important and costly than benefits of providing shadow in summer.

Block A1 with 300 residential units has been chosen among the whole residential complex as the case study.

This block is composed of both high rise buildings with the height of 12 floors and low rise building with the height of 6 floors. (Figure 2).

Figure2 Geometry model of the case study block for simulation

The temperature inside the residential building is directly related to the amount of thermal energy that enters through windows. For this reason, in order to measure the negative impacts of buildings on each other, the amount of shadowing that they make on each other should be calculated. If this amount becomes less; it means the number of hours that the space is under direct sunlight per day is more and as a result, the space gets more benefits from thermal energy of sun. On the contrary, if this amount gets higher, it means that the negative effects of shading caused by adjacent blocks would be higher.

Traditional regulations for controlling the impact of shading

Basically, there are some regulations for controlling the impacts of shading of construction blocks on each other. As a rule, distance of two adjacent buildings (two buildings in north and south direction of each other) should be more than one-fifth of the height of the southern building. For two buildings that are not completely in south and north directions of each other, this distance should be controlled by drawing a circle with a radius of one-fifth of the height of southern building. In common existing methods in Iran, controlling the shades is completely done manually without the use of computer modelling in any level of related process. Obviously, this regulation has some disadvantages. For instance, it estimates shading of one block on another one in a given time, for example, the afternoon of first day of winter. Thereby, it could not be generalized to all hours of the day and all days of a year. It is clear that making decisions based on shading of a specific hour or day is not correct, because it does not give us comprehensive perception on the amount of the shadowing of the two blocks on each other. (Bavand consultants, 2010), (Figure 3).

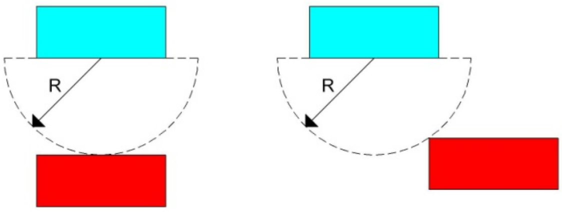


Figure3 Traditional regulations for controlling the impact of shading of construction blocks on each other

The other disadvantage of basic method is its dialectic logic. The result of shade control might be totally change by only a one- centimetre movement in the building's place. Besides, this method is useful just for simple separated blocks and it does not work for more complicated building compositions. All the weak- points of basic method were the reasons for developing a comprehensive computer–based analysis system for convincing the employer and city government to permit construction of such complex.

Clearly, in order to complete this analysis, computer and suitable simulation programs should be used. The algorithm for this project has been written in Rhino Script programming environment, which is a plug-in for Rhino software. After testing, this program can be used as a plug-in in Rhino program environment and be accessed by architects and other users of this program. Nowadays many architects use Rhino for modelling, so this plug-in has some advantages in comparison with the other analytical programs. The inputs of this program are the geometric contour of the blocks, location of the windows and required precision for the calculation. This program has the ability to do the calculation with different precisions; for example every 30 minutes or every minute; and for different time intervals; like one day or one season or one year. The output is a graphical diagram that shows the amount of sunlight received by the window per hour in the shape of a colourful sphere during the day. In addition, the program has the ability to do that calculation for any time interval for example winter season or all days of the year. Another output of this algorithm is digital information that gives the alternatives for making decisions in different stages of design. These numeral data can show us, for example, the average number of hours the windows get the benefit of direct solar radiation. It also shows the percentage of the windows which their received solar radiation is less than a specific number of hours. For example; 30 percent of the windows get solar radiation less than 200 hours in a year.

These charts make it possible for the managers to define their regulation based on the real variables. For example they can edit the rule about shading which were mentioned above. Thereby, a building block may have the construction permission on the condition of having the benefit of solar radiation in 50 percents of whole sunny hours through 90 percent of its windows.

The location of sun

In order to calculate the sunshine amount in a specific time and geographic point, the location of sun must be known.

The location of sun is specified by two indicators of “radiation angle” and “radiation direction”. Daily and annual changes of the two indicators depend on the geographic latitude of the place. In many countries, these two indicators have already been calculated and presented for various points and different times in form of tables and curves. On the other hand, if the sun location for a specific region is needed, mentioned points could be obtained through mathematical calculations. (Figure 4).

The first effective factor in calculating the sun location is the angle of earth rotation. Through the year, this angle changes 47 degrees from 23.5 degree upward of the tropical plate to 23.5 degree downward of the tropical plate. The other effective factors are the geographic altitude and the time. Having all these information.

we can estimate the two above-mentioned angles according following Equations:

$$\sin \phi_s = \frac{-\sin h \cos \delta}{\cos \theta_s}$$

$$\cos \phi_s = \frac{\sin \delta \cos \Phi - \cos h \cos \delta \sin \Phi}{\cos \theta_s}$$

ϕ_s is the solar azimuth angle
θ_s is the solar elevation angle
h is the hour angle, in the local solar time
δ is the current sun declination
Φ is the local latitude

Since each day (and night) is 24 hours and earth rotates 360 degrees during this time, then it rotates 15 degrees per hour. This angle is always calculated through sun’s location in the noon.
(Kasmai, 2007)

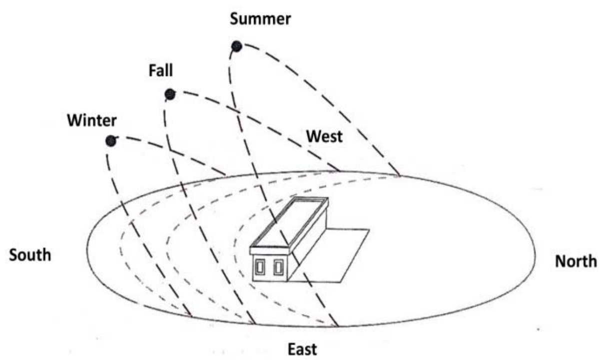


Figure 4 The place of sun in different seasons

The simulation algorithm

The algorithm of this program is formed by calculation of coordination of solar radiation vector in different hours and days in a specific time interval. This algorithm is developed in Rhino script plug-in of Rhino software. (Figure 5).

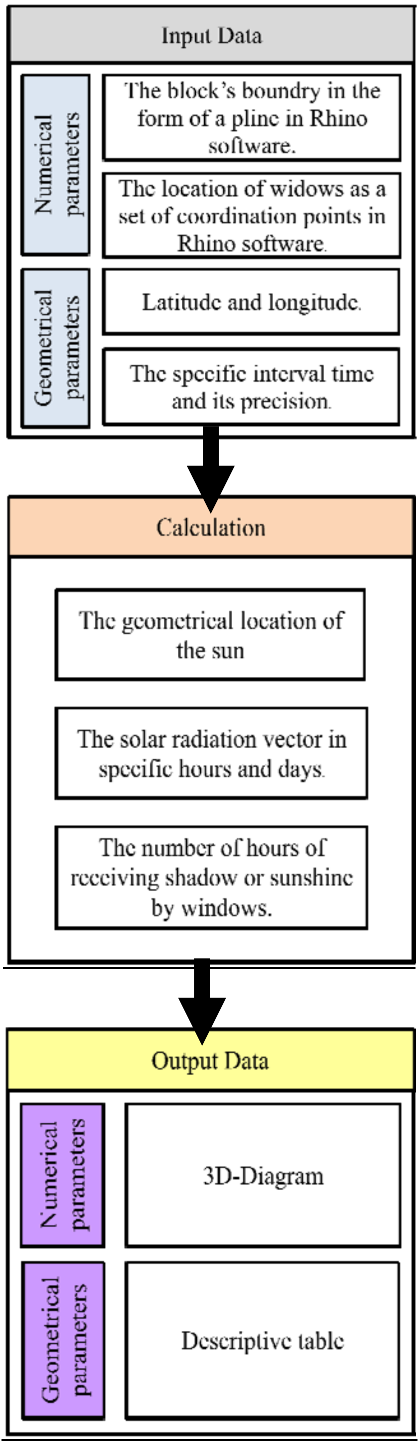


Figure5 simulation algorithm

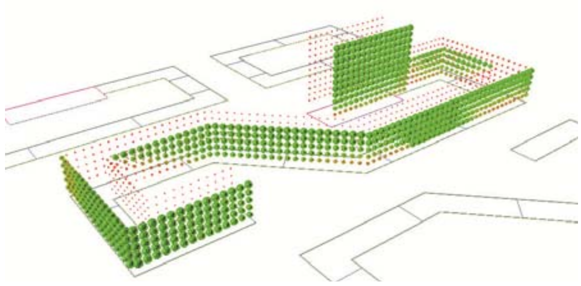
RESULTS AND ANALYSIS

In order to measure the amount of direct sun light received by each window, a simulation algorithm (figure 5) is designed. This algorithm can calculate the radiation angle in different hours of a day and different days of a year. With evaluating the radiation vector of the sun and the location of the building's blocks, it can obtain the number of hours that the radiation vector has been received by a particular window.

This data can be calculated for any particular window of blocks in different hours and days. What would be found by these data is the real amount of blocks shading on each other. This helps the architects to find the real influence of blocks on each other in the form of numerical data. They can use this information through the designing process. For example, they make the shadow amount as less as they can by changing the arrangement of blocks, their heights and dimensions. They also can use the data to detect the design's weakness (such as the windows received less than standard amount of sunlight during a day) and consequently use other methods such as special isolating or using extra heating system to solve the problem.

The first column of each table in figures 6-12 shows the ranges defined for the hours of receiving solar radiation. The second column shows the number of windows receive the defined amount of sunshine. The third column is an index for the percentage of windows get the advantage of sunlight and the last column indicates the additive percentages. This column can give us the most comprehensive information. For example on December first (first day of winter), 47.89 percent of windows get the benefit of direct sunlight at list 3 hours of a day.

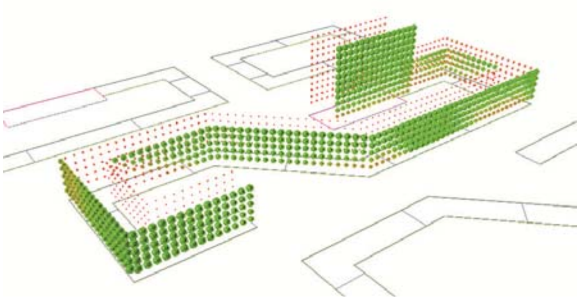
The diagrams and tables in figure 6 to 12 have been extracted from special days but there is the possibility to extract them from any other different time interval in this software as well. (Figure 6-12).



21 December

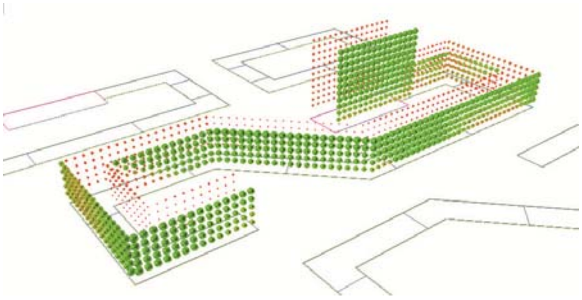
Hours / Day	Number of Windows	Percentage	Additive Percentage
0-1	336	22.11	100.00
1-2	355	23.36	77.89
2-3	101	6.64	54.54
3-4	19	1.25	47.89
4-5	49	3.22	46.64
5-6	82	5.39	43.42
6-7	101	6.64	38.03
7-8	175	11.51	31.38
8-9	279	18.36	19.87
9-10	23	1.51	1.51
10-11	0	0.00	0.00
11-12	0	0.00	0.00

Figure 6 Solar absorption in 21 December



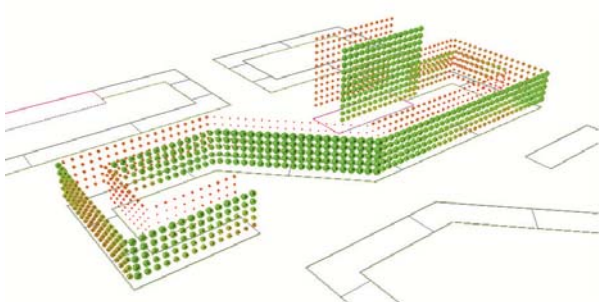
20 January & 21 November			
Hours / Day	Number of Windows	Percentage	Additive Percentage
0-1	280	18.42	100.00
1-2	71	4.67	81.58
2-3	416	27.37	76.91
3-4	38	2.50	49.54
4-5	38	2.50	47.04
5-6	88	5.79	44.54
6-7	102	6.71	38.75
7-8	139	9.14	32.04
8-9	168	11.05	22.89
9-10	180	11.84	11.84
10-11	0	0.00	0.00
11-12	0	0.00	0.00

Figure 7 Solar absorption in 20 January & 21 November



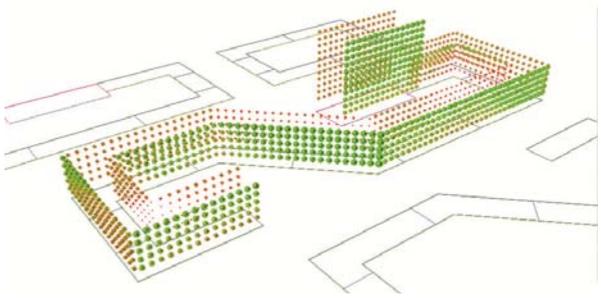
19 February & 22 October			
Hours / Day	Number of Windows	Percentage	Additive Percentage
0-1	189	12.43	100.00
1-2	54	3.55	87.57
2-3	407	26.78	84.01
3-4	139	9.14	57.24
4-5	32	2.11	48.09
5-6	92	6.05	45.99
6-7	119	7.83	39.93
7-8	119	7.83	32.11
8-9	288	18.95	24.28
9-10	62	4.08	5.33
10-11	19	1.25	1.25
11-12	0	0.00	0.00

Figure 8 Solar absorption in 19 February & 22 October



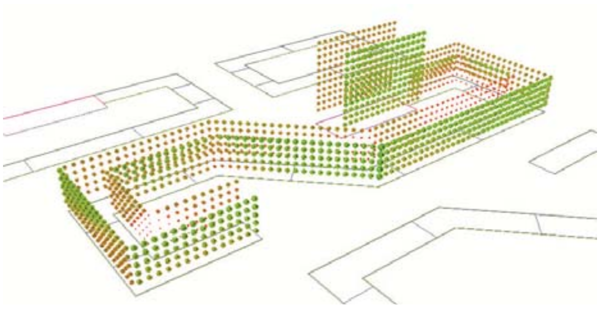
22 September & 20 March			
Hours / Day	Number of Windows	Percentage	Additive Percentage
0-1	155	10.20	100.00
1-2	48	3.16	89.80
2-3	65	4.28	86.64
3-4	350	23.03	82.37
4-5	195	12.83	59.34
5-6	103	6.78	46.51
6-7	100	6.58	39.74
7-8	122	8.03	33.16
8-9	282	18.55	25.13
9-10	19	1.25	6.58
10-11	37	2.43	5.33
11-12	44	2.89	2.89

Figure 9 Solar absorption in 22 September & 20 March



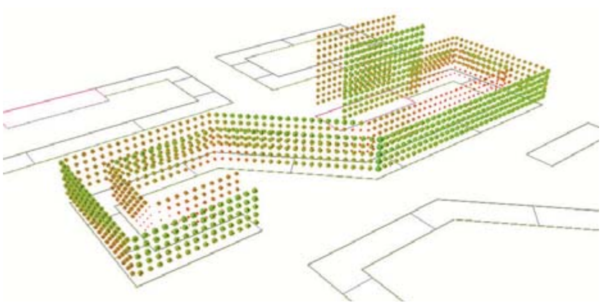
22 August & 20 April			
Hours / Day	Number of Windows	Percentage	Additive Percentage
0-1	30	1.97	100.00
1-2	43	2.83	98.03
2-3	121	7.96	95.20
3-4	88	5.79	87.24
4-5	55	3.62	81.45
5-6	545	35.86	77.83
6-7	94	6.18	41.97
7-8	175	11.51	35.79
8-9	293	19.28	24.28
9-10	24	1.58	5.00
10-11	47	3.09	3.42
11-12	5	0.33	0.33

Figure 10 Solar absorption in 22 August & 20 April



21 May & 22 July			
Hours / Day	Number of Windows	Percentage	Additive Percentage
0-1	25	1.64	100.00
1-2	2	0.13	98.36
2-3	102	6.71	98.22
3-4	53	3.49	91.51
4-5	53	3.49	88.03
5-6	446	29.34	84.54
6-7	281	18.49	55.20
7-8	192	12.63	36.71
8-9	361	23.75	24.08
9-10	0	0.00	0.33
10-11	2	0.13	0.33
11-12	3	0.20	0.20

Figure 11 Solar absorption in 21 May & 22 July



21 June			
Hours / Day	Number of Windows	Percentage	Additive Percentage
0-1	25	1.64	100.00
1-2	7	0.46	98.36
2-3	63	4.14	97.89
3-4	71	4.67	93.75
4-5	54	3.55	89.08
5-6	82	5.39	85.53
6-7	577	37.96	80.13
7-8	246	16.18	42.17
8-9	390	25.66	25.99
9-10	0	0.00	0.33
10-11	2	0.13	0.33
11-12	3	0.20	0.20

Figure 12 Solar absorption in 21 June

The other application of this program is calculating the amount of block's shadow on the ground. This parameter is important because in cities with cold climate like Karaj, there are several days of a year that ground would be covered by ice and snow. Therefore, block's shadow makes the ice coverage of the ground longer and as a result, there would be so many transportation problems.

This program calculates the number of hours that each point on the earth gets the benefit of sunlight and shows that in a diagram. Three different arrangements of the blocks which have been analysed by this software is shown below. These analyses can help the designer to choose the optimum alternative and then he can find the places with the more duration of ground frost. This point should be mentioned that this software is a simulator not an optimizer and the designed alternatives can be analysed and compared with its abilities. (Figure 13-15).

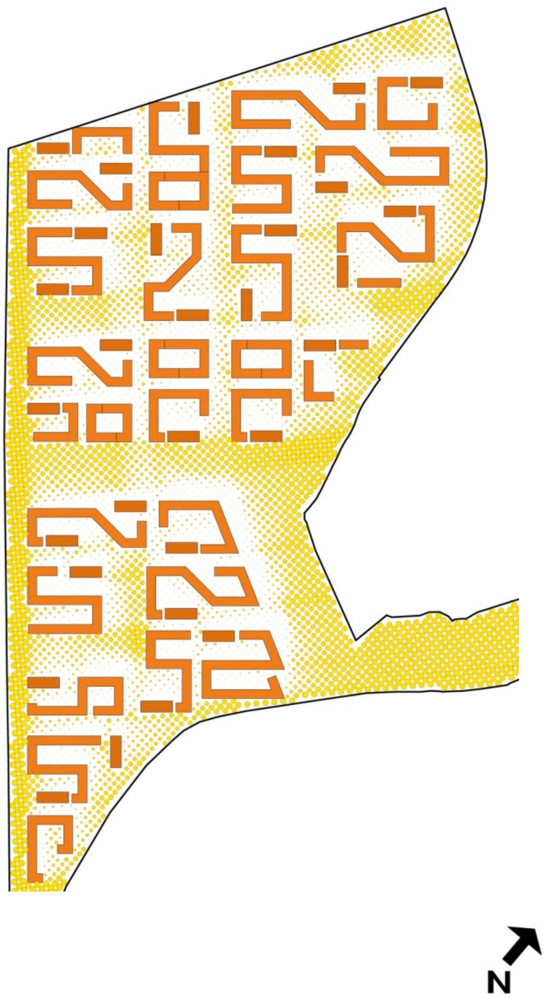


Figure 13 Comparison of solar absorption in site plan (Alternative1)

Figure 14 Comparison of solar absorption in site plan (Alternative 2)

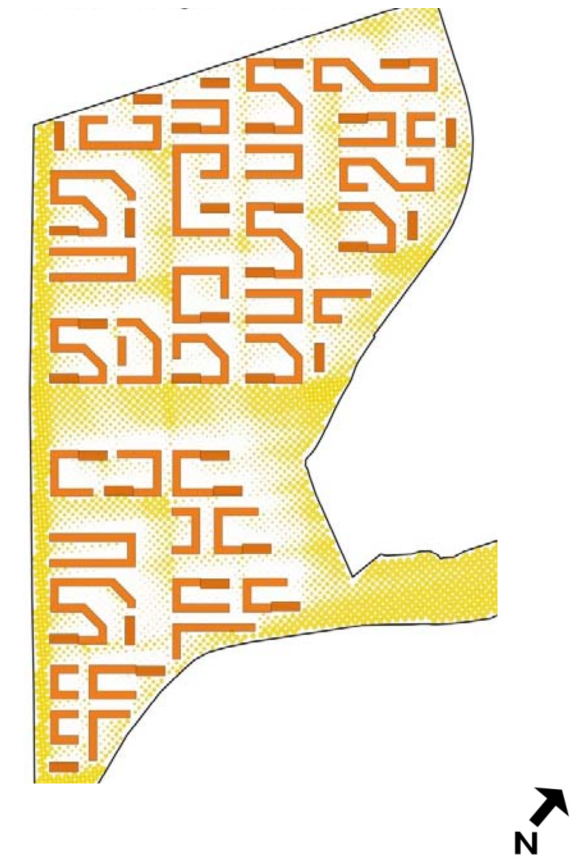


Figure15 Comparison of solar absorption in site plan (Alternative 3)

CONCLUSION

The exact and real amount of shadows in north hemisphere cannot be found by mathematical formulas and comparing the distance between two blocks and the height of southern block.

For exact measuring of amount of shadow and finding the appropriate height and arrangement of blocks, a geometrical model of designed blocks and the location of sun and radiation angles are needed. The result of this simulation can provide tables and comparative diagrams needed for the design process to choose the optimum alternative.

REFERENCES

Golabchi, M, Andaji Garmaroodi, Ali, Bastani, Hosein, Digital Architecture (2011), Tehran University Publication, Tehran, Iran.

Kasmai.M ,Climate & Architecture, Second Edition ISBN (2007) 964-5583-47-0.

Bavand Consultants, General urban plan of Karaj, (2010).

Jensen, S.Q. 1994. Validation of building energy simulation programs a method, Thermal Insulation Laboratory, Technical University of Denmark, Building 118, DK-2800 Lyngby, Denmark.

WARD, J.C., L0F, G. 1975. Long- term (18 years) of a performance of a residential solar heating system, Solar Energy Applications Laboratory, Colorado State University, Fort Collins, CO 80523, U.S.A.

Galasiu, A.D., Atif, M.R., & R.A. MacDonald, "Impact of window blinds on daylight-linked dimming and automatic on/off lighting controls", National Research Council Canada – 46780, 2004.

Sims, L., "Enhance User Satisfaction, Performance with Daylighting", Research & Development, 109-110, 2002.

Johansson, E. 2005.Influence of urban geometry on outdoor thermal comfort in a hot dryclimate: A study in Fez, Morocco, Housing Development & Management, Lund University, PO Box 118, SE-221 00 Lund, Sweden.

Toudert, F.A., Mayer, H. 2005. Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort inhot and dry climate, Meteorological Institute, University of Freiburg,Werderring 10, D-79085 Freiburg, Germany.

Gulyas, A., Unger, J., Matzarakis, A. 2006. Assessment of the microclimatic and human comfort conditions in acomplex urban environment: Modelling and measurements, Building and Environment 41: 1713–1722.

Hwang, R.l., Lin, T.P., Matzarakis, A. 2010. Seasonal effects of urban street shading on long-term outdoor thermal comfort, Building and Environment 46 :863e870.

Lund, P.D. 1985. Computational simulation of district solar heating systems with seasonal thermal energy storage, Solar Energy, 36. 5: 397-4