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Recognition of the Quality of Sunlight Hours in Traditional Houses of Tabriz, Iran*

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Abstract

Attention to daylighting methods in traditional houses is one of the prominent features of the rich vernacular architecture of Iran. Therefore, recognizing the experiences of the predecessors about the transparent surfaces of the indigenous houses of Tabriz city which is located in the cold-dry climate of Iran and updating the previous strategies can improve the quality of daylight in contemporary buildings.

This paper examines physical elements of the open and closed spaces in the traditional houses of Tabriz and their role in increasing the quality of daylighting and sunlight hours in the interior spaces, analyzes the logical relationship between the components of transparent surfaces and the closed spaces associated with them.

The purpose of this study is to recognize quality and sunlight hours of traditional houses of Tabriz and to provide suggestions and design patterns for closed spaces in this city buildings and cold-dry climate buildings in Iran. The research method is based on data collection, field studies and the use of daylight analysis software to check the illuminance of the spaces, sunlight hours and shading in the yard throughout the year. Standards related to daylight quality and statistical methods were used to analyze the obtained information. The results indicate the existence of a logical relationship between some elements of window and room in the closed spaces related to windows that provide adequate daylight, which is presented as proposed design patterns.

Keywords: Sunlight Hour; Daylighting; Transparent Surfaces; Traditional Houses; Tabriz; Design Pattern

Introduction

In the absence of daylight, which is a combination of the sunlight, light of the sky, and the light reflected from the ground and surrounding objects, humans lose their sight. Humans are capable of seeing lights with wavelengths between 400 nm and 700 nm. Indeed, sight is the ability to obtain information through the light entering the eyes. Based on the conducted studies, undeniable evidence has been obtained of the positive effect of daylight and natural landscape on the physical and mental health, comfort, and efficiency of individuals. Table one mentions some of these studies [1-8]. Humans

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have always been interested in the special importance of the sun and the light produced by it.

Table 1. Some of Studies done in the field of Effects of daylight on the health of human body and soul.

Researcher / year	Source
N. Miller. 1994.	Pilot Study Reveals Quality Results
Kevin Mc Cloud. 1995.	Lighting Style
Craig DiLouie. 2002.	Lighting & Productivity
Jacob Liberman. 2002.	Light: Medicine of Future
Gregory Franta & Kristine Anstead. 2003.	Daylighting offers Greate Oppertunities
Fereshteh Nayebi & et al. 2008.	The effect of indoor lighting on quality of life and human moral behaviors
Shahram Pourdeihimi & Fariborz Hajiseyed Javadi. 2008.	Daylight and the human being: perception and biopsychology of daylight
M. Ouria & et al. 2018.	Lighting Quality and Human Health Problems in Man-made Environment

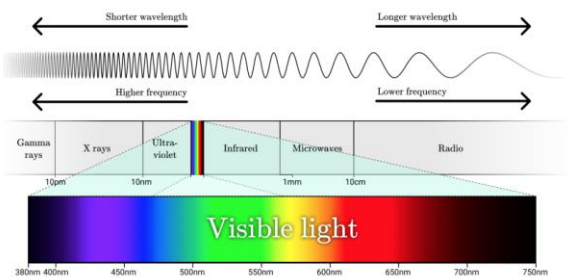


Figure 1. Electromagnetic Spectrum

Given the abundance of daylight in Iran, the residence history, and the valuable architecture of the country, lighting was an important component of Iranian architecture in the past.

Despite limited studies carried out on the spaces of traditional houses in the hot and dry climate of Iran, [9-21] a rational relationship has been identified between the physical elements of spaces and the amount of lighting in them. However, no study has been performed on the effect of sunlight hours and their amount on the windows of spaces. Moreover, there is no information about the quality of spaces in terms of the amount of illuminance and sunlight hours in the traditional houses of the cold region of Iran. By evaluating the number of sunlight hours, components of translucent surfaces and main spaces of the traditional houses of Tabriz, located in the cold climate of Iran, this study answers the following questions:

- Is the number of sunlight hours in the spaces of vernacular buildings of Tabriz favorable?
- Is there a logical relationship between the components of translucent surfaces and spaces with the favorable number of sunlight hours?

2. Materials and Methods

2.1. Climate and vernacular architecture of the cold region of Iran

In his book “Climatic Zoning of Iran, Housing, and Residential Environments”, Mortaza Kasmaei has divided Iran into four climatic classes [22]. Another climatic zoning proposed by Mansoureh Tahbaz with the cooperation of Shahrbanou Jalilian has divided the climate of Iran into six classes [23]. According to this classification, the study area has the climate of tall and semi-tall mountainsides, including cities like Ardabil, Tabriz, Sanandaj, Kermanshah, Mashhad, and Zanjan. Based on the studies performed by the Road, Housing & Urban Development Research Center of the Ministry of Roads and Urban Development in Iran, the climatic zoning map of Iran has been prepared in which the country is divided into eight climatic zones [24]. Figure 2 shows the cold climatic zone of Iran.

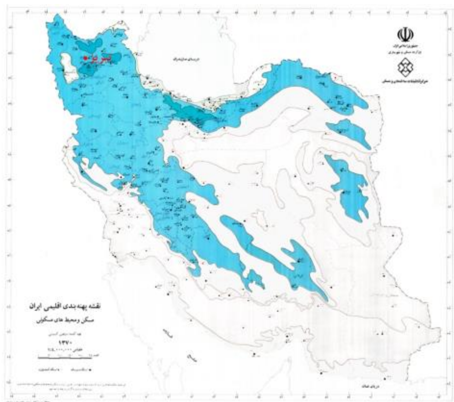


Figure 2. Climate zoning map of Iran [24] (Cold zone)

In these areas, the windows are not much small. Therefore, in winter, more sunlight, and in warm periods, a larger volume of favorable cool winds can enter the rooms [23]. In the mountainsides and cold areas of Western Iran, the tall two-edge windows are more frequent. Such windows receive the solar heat from the southern yards and make air draught with the backyards. In cold areas, the windows are positioned on the exterior edges of the frames [16].

2.2. Sunlight hours in the cold area of Iran

The sunlight hours in a day equals the duration within the day in which the sun is in the sky, and it is not hidden by the clouds [25]. The number of sunlight hours is considered the main factor controlling the life, climate, and other biological activities on the earth [26]. According to studies investigating the number of sunlight hours in 87 synoptic stations of the country in a 20-year period (1986-2005), the average annual number of sunlight hours was 2954 hours. The central and southeastern areas had the highest numbers, while the northern coasts of the country had the lowest values [27]. Other credible reports also approve an average annual number of more than 2900 for the sunlight hours in Iran [28]. In general, from the north to the west and from the west to the east, the number of sunlight hours increases, while its variation declines [27]. Zones 2 and 5, which include the cold climate of Iran and are entitled the northwest-northeast or northwest areas, have an acceptable number of annual sunlight hours compared to the average annual number of the whole country.

Table 2. Total sunlight hours in provincial centers in 2016 [29]

City	Total sunlight hours
Ardebil	2671
Ourmiyeh	2902
Tabriz	2784
Zanjan	2850
Sanandaj	2970
Kermanshah	2980
Mashhad	3101
Hamedan	3013

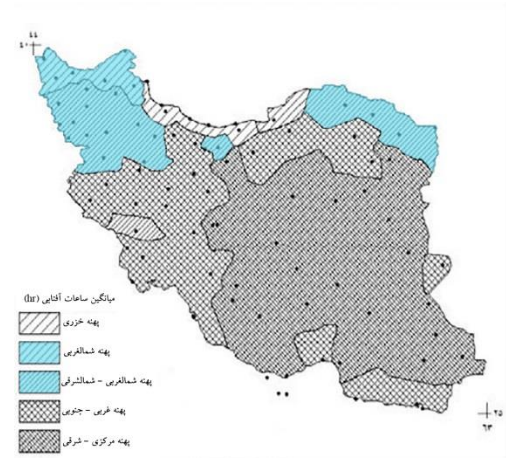


Figure 3. Zoning of Iran based on the average annual sunlight hours [27]

Table 3. Zoning characteristics of the amount of annual sunlight hours in Iran [27]

Zone name	Number of Stations	Percent. country area	Aver. of SL hours	Max	Min
Cen.-E	26	49.3	3230	3408	3220
NW-NE	20	14.8	2857	2925	2743
W-S	27	29.5	3092	3208	2944
Khazari	7	2.1	1820	2014	1587
NW	7	4.3	2475	2654	2200

2.3. Standards of daylight and sunlight hours in Iran and the world

Given the increasing importance of the daylight in building design to reduce the costs and improve the visual and spiritual comfort of humans, public and private organizations and institutes in different countries have provided suggestions and standards for daylight design in residential and working spaces. At first, the attention was mostly given to the role of the sun as a renewable energy resource to reduce the costs of buildings. Then, the effect of daylight on the human health was discussed, and researchers sought to provide solutions to use the daylight for the comfort of residents. In order to identify the favorable spaces in terms of daylight, these spaces are analyzed from four major dimensions: 1) Quantity of Illuminance,
2) Uniformity of daylight, 3) Number of sunlight hours, 4) Outside view.
In order to obtain a more reasonable answer in this study, in addition to the rules and standards of Iran,

the requirements of daylight and number of sunlight hours in eleven other countries with cold climates, as shown in Table 4, were evaluated [30-52].

Table 4. Cases studied in the field of daylight quality in the standards of the studied countries

Country	Standards	Illuminance	Uniformity of daylight	Sunlight	View out
Iran	National Building Regulations, 4		■		
	National Building Regulations, 13	■			
European Union	EN 12464-1: 2011 (E)	■			
	prEN 12464-1: 2019 (E)	■			
	EN 17037: 2018 (E)	■		■	■
	BS 8206-2: 2018	■	■	■	■
Britania	CIBSE (SLL) code for lighting: 2012	■			■
	CIBSE -Lighting Guide LG10: 1999	■	■		■
	CE 257: 2007	■			
	IECC: 2018		■		
USA	ASHRAE 90.1: 2010		■		
	IES RP-5-13: 2013	■			
	The WELL Building (IWBI): 2020	■	■		■
Island	ÌST-EN 12464-1: 2011	■			
	Icelandic Building: 2016		■		
Denmark	BR10: 2010	■	■		■
	BR18: 2018 (EN2018)	■		■	■
Sweden	MILJÖ Byggnad 3.1: 2020	■	■		■
	BFS: 2014	■	■	■	
Finland	RT 07-10912: 2008	■	■		■
Norway	Norwegian Building: 2010	■	■		
	TEK17: 2017	■	■		
	NS- EN 12464-1: 2011	■			
Stonia	EVS 894:2008/A2:2015	■		■	
Germany	DIN 5034-1: 2019-12	■		■	
	DIN EN 12464-1: 2011	■			
	DIN EN 17037: 2018	■		■	■
Austria	SLG 101: 1997	■			■
	SN EN 12464-1: 2013e	■			
	SN EN 17037: 2018	■		■	■
Poland	Act Building law: 1994	■	■	■	■
	Polish Building Regulation :2013		■	■	■

Among these standards, those of the European Union, UK, Denmark, Sweden, Germany, Switzerland, and Poland have defined minimums for the number of sunlight hours per month or season. The presence of at least one space with the minimum quality of sunlight hours in each building is mandatory in all standards. Moreover, in all standards except for that of the European Union, the criterion to evaluate the number of sunlight hours is the centers of windows. In the latest edition of the Europe daylight standard, the evaluation point is at a height of 1.2 m in the center of windows, as shown in Figure 4 [33]. In order to evaluate and validate the spaces investigated in this research, each item of the daylight in standards was ranked according to the intended quality. For instance, Table 5 shows the details of sunlight hour quality requirements in the European Union standard: EN 17037: 2018 [33].

2.4. Evaluation of the selected samples

Three factors were considered in choosing the samples: 1) Construction time, 2) Accessibility and assessability, 3) Intactness of the building structure. The variable construction time was considered constant, and given the ancientness and dispersion of the intact buildings of the Qajar era, which were the continuance of the Azari and Isfahani style and a combination of the original Iranian architecture and the modern architecture, the entire buildings chosen to be studied in this research belonged to this era. In this study, a total of ten Qajari houses of the city of Tabriz in the northwest and cold climate of Iran with a longitude of 46.3E and a latitude of 38.1N were chosen to be assessed.

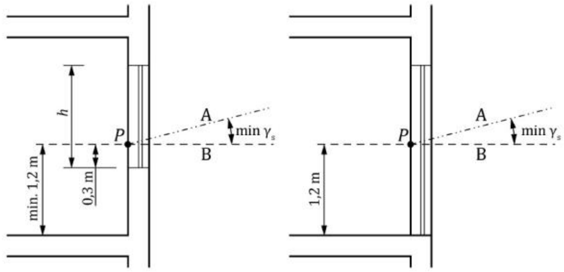


Figure 4. Position of the reference point *P* in section [33] (A: minimum solar altitude. B: horizon. γ_s: solar altitude.)

Table 5. Sunlight hours quality requirements in the European Union standard: EN 17037: 2018 [33]

Grade	Quality	Hours	Day	Hours	Day
0	Bad	<1.5h	1Feb	<1.5h	21Mar
1	Min.	1.5h	1Feb	1.5h	21Mar
2	Med.	3.0h	1Feb	3.0h	21Mar
3	High	≥4.0h	1Feb	≥4.0h	21Mar

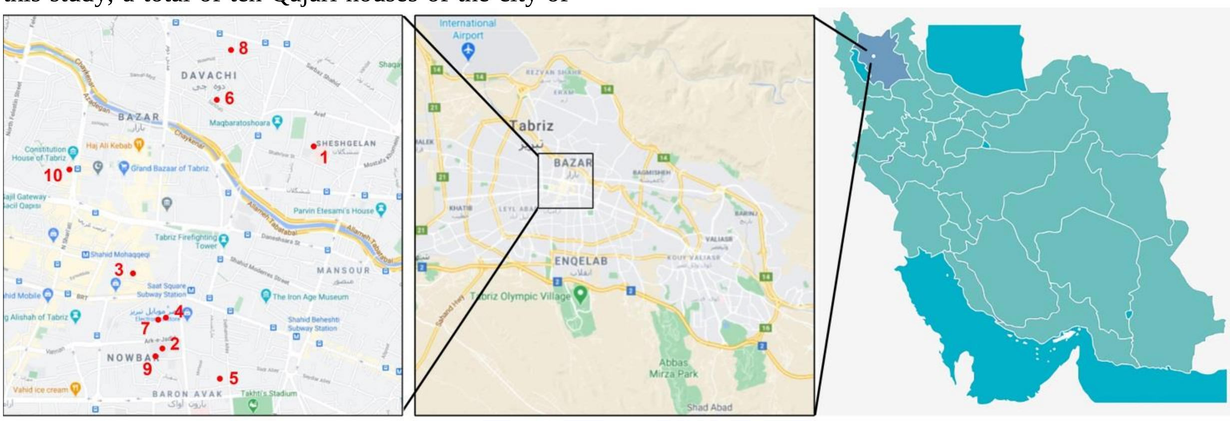


Figure 5. Location of selected houses in Tabriz. 1) Amirnezam 2) Behnam 3) Hariri 4) Heidarzadeh 5) Khatayi 6) Sorkheyi 7) Salmasi 8) Alavi 9) Gadaki 10) Mashroteh

Table 6. Current and Previous Function of selected traditional Houses in Tabriz

Houses	Current Function						Previous Function	Renovated
	Abandoned	Hotel Restaurant	Museum	Official	Cultural Educational	Residential	Residential	
Amirnezam			■				■	■
Behnam					■		■	■
Hariri			■				■	■
Heydarzadeh				■			■	■
Khatayi					■		■	■
Sorkheyi	■						■	■
Salmasi			■				■	■
Alavi			■				■	■
Gadaki					■		■	■
Mashroteh			■				■	■


Figure 6. South courtyard of Behnam traditional house in Tabriz

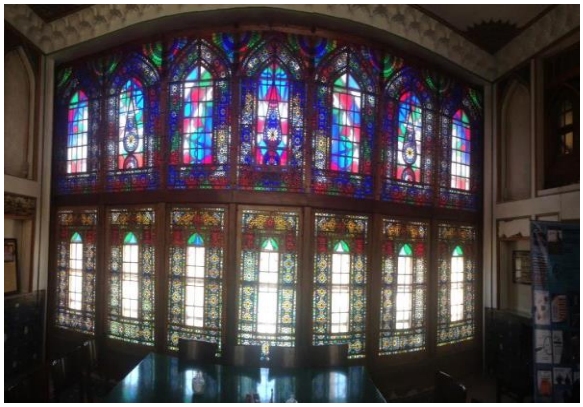


Figure 7. Interior of Room No. 2 of Behnam traditional house in Tabriz

In general, the factors which affected choosing the location side of buildings include: Solar radiation, Wind direction, and Qibla direction. The average orientation of the main side of houses in Tabriz was considered in a range from 16° SE to 15° SW. (Figure 8) Half of samples had a SE orientation while the other half had a SW one. The average open space was 46%, and the average closed space was 54%. Furthermore, the average ratio (length to width) and average depth (length to height) of yards in the chosen samples of Tabriz were respectively 1.0 and 3.7. The average longitudinal and transverse visual angles were also 14.7° and 17.5°, respectively. Table 9 lists the analysis results of the of transparent surfaces of the chosen buildings, separately.

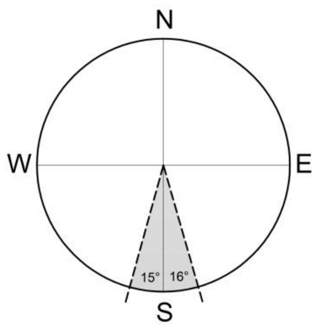


Figure 8. Position angle in selected traditional houses of Tabriz

Table 7. Introducing the selected houses in Tabriz

House	Perspective	Open & Close	Floors	Plan and yard Sorting	Orientation	Location
Amirnezam						
Behnam						
Hariri						
Heydarzadeh						
Khatayi						
Sorkheyi						
Salmasi						
Alavi						
Gadaki						
Mashroteh						

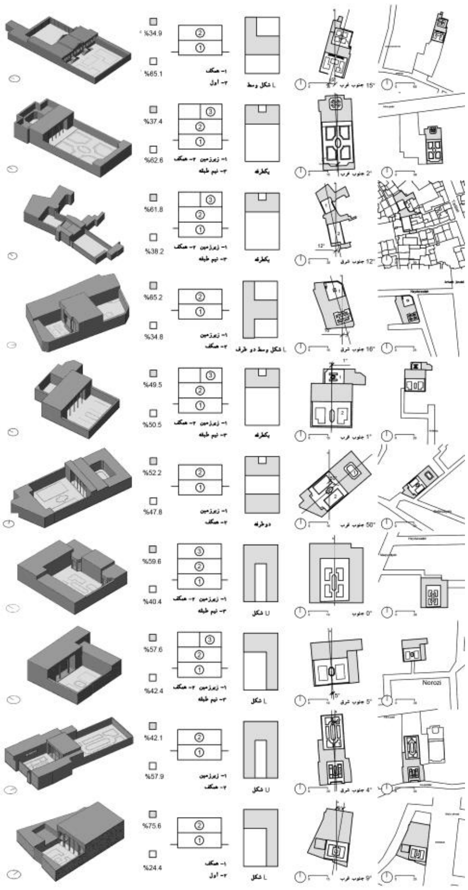


Table 8. Sample formal analysis of selected House yards in Tabriz (Behnam traditional house)

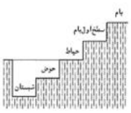
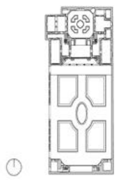
Elevation pattern	Yard level difference	Transverse viewing angle	Longitudinal viewing angle	Length to height	Length to width	Plan	House
	-0.3	12	10	5.37	1.47		Behnam

Table 9. Analysis of transparent surfaces facing the yard in selected traditional houses of Tabriz

House	Elevation	Ele. Area (m^2)	Transparent (m^2) Area	Transparent percent	All Transparent percent
Amirnezam	S	283	87	31	24
	N	271	72	27	
	E	157	35	22	
	W	176	16	9	
Behnam	S	230	83	36	30
	N	77	19	25	
	E	45	9	19	
	W	45	9	19	
Hariri	S	110	24	22	17
	N	75	7	10	
	E	-	-	-	
Heydarzadeh	S	122	49	40	28
	N	125	24	19	
	E	151	39	26	
	W	-	-	-	
Khatayi	S	191	61	32	24
	N	94	9	10	
	E	-	-	-	
	W	43	9	20	
Sorkheyi	S	296	83	28	23
	N	90	14	15	
	E	52	9	18	
	W	52	7	13	
Salmasi	S	113	50	44	28
	N	-	-	-	
	E	122	19	16	
	W	146	36	25	
Alavi	S	150	43	28	25
	N	-	-	-	
	W	82	15	18	
Gadaki	S	176	56	32	26
	N	233	65	28	
	E	153	36	23	
	W	153	27	17	
Mashroteh	S	217	70	32	27
	N	30	7	22	
	E	65	8	13	

The spaces associated with transparent surfaces in buildings were divided into two major classes of open and closed spaces. All yards of the chosen buildings were evaluated as open spaces. The rooms to be investigated were chosen with respect to the following points: 1) At least one space of each orientation of rooms and windows in buildings, 2) Rooms with particular position and windows like sashes, 3) Not choosing similar spaces. A total of 48 rooms and 10 yards were investigated in this research.

After the spaces were chosen, the whole information of their physical elements was collected and classified separately for the open and closed ones.

- **Open spaces**: 1) Open space area, 2) Ratio of open to closed area, 3) Yard ratios, 4) Average depth, 5) Yard shape, 6) Number of sunlight and shading hours in yard, 7) Longitudinal and transverse viewing angles, 8) Area of opaque and transparent facades toward yard, 9) Area of gardens, 10) Area of fountains. (Figure 10)
- **Closed spaces**: 1) Orientation and location of rooms and windows, 2) Dimensions and area of rooms, 3) Dimensions and area of windows, 4) Shape and type of windows, 5) Visible sky angles in section and facade, 6) Sky mask percentage, 7) Horizontal viewing angle at the end of working surface, 8) Distance between windows and view obstruction, 9) View layers in section, 10) Light penetration depth. (Figure 11)

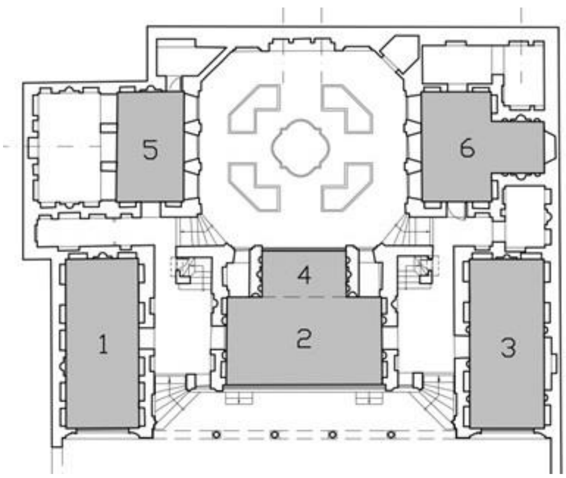


Figure 9. Sample selected rooms for review (Behnam traditional house)

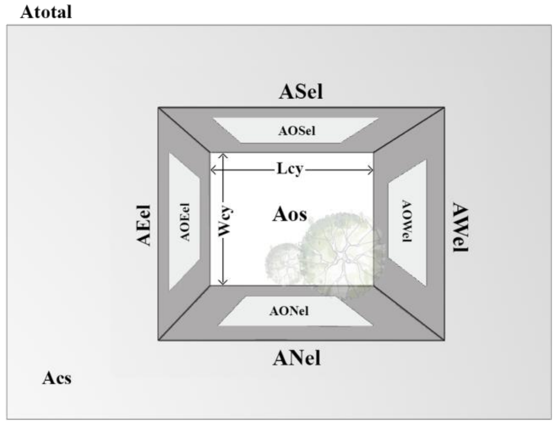


Figure 10. Physical elements of outdoor space

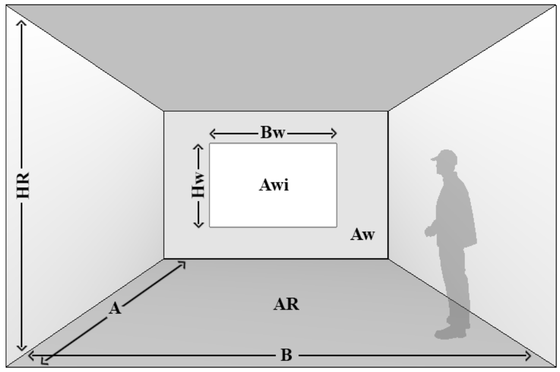


Figure 11. Physical elements of indoor space

By using the obtained information, the volumetric plot of buildings was performed in AutoCAD and 3D Max software programs. By using the Ladybug add-on in the Grasshopper and Rhino programs, which employs advanced daylight analysis engines, the shading percentage in yard per year was obtained. Moreover, the Ecotect software was used to analyze the daylight and number of sunlight hours on the windows of the chosen spaces. The extensive use of this software in the initial and final phases of design is emphasized [53].

According to Figure 13, the average full and partial shade percentages of yards in the studied houses were 20.0% and 80.0% in the spring equinox, 1.2% and 97.4% in the summer solstice, 19.8% and 80.1% in the autumn squinox, and 58.9% and 41.1% in the winter solstice, respectively. Only in Khatai House, there was a full sunshade of 10.6% in the yard in the summer solstice.

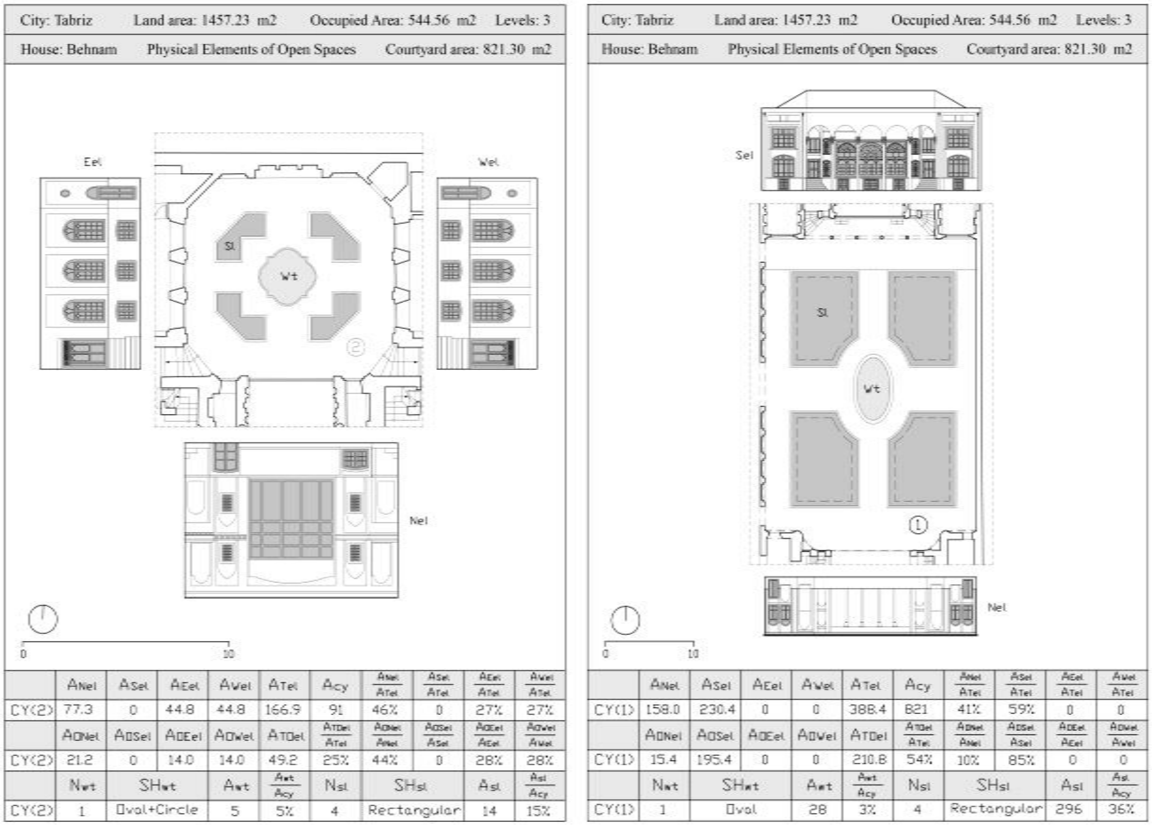


Figure 12. Sample data collection of physical elements of open spaces of selected Houses in Tabriz (Behnam traditional house)

Table 10. Sample analysis of shadow hours in the yards of Selected houses in Tabriz (Behnam traditional house)

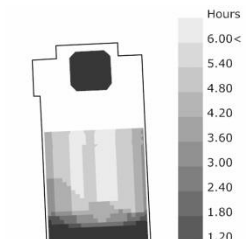
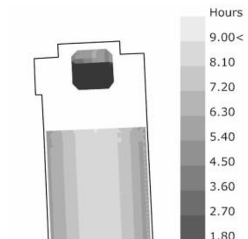
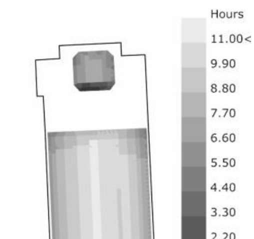
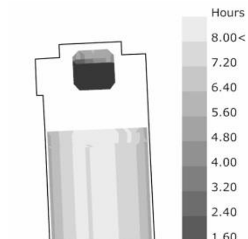
Day	21 December			22 September			21 June			20 March		
Shading during the day												
Day hours	09:31	Rise 07:37	Sunset 17:08	12:11	Rise 06:12	Sunset 18:22	14:49	Rise 06:02	Sunset 20:50	12:07	Rise 06:29	Sunset 18:36
Shadow	Full	Half	Zero	Full	Half	Zero	Full	Half	Zero	Full	Half	Zero
Shading area in the yard (%)	41.1	58.9	00.0	17.6	82.4	00.0	00.4	99.6	00.0	17.4	82.6	00.0

Table 11. Analysis of sunlight hours in the selected courtyards of Tabriz traditional houses

House	Shadow persent	20 Mar.	21 Jun.	22 Sep.	21 Dec.	House	Shadow persent	20 Mar.	21 Jun.	22 Sep.	21 Dec.
Amirn.	Full	4.5	-	6.2	56.8	Sorkheyi	Full	13.5	1.3	14.0	61.2
	Half	95.5	100	93.8	43.2		Half	86.5	98.7	86.0	38.8
	Zero	-	-	-	-		Zero	-	-	-	-
Behnam	Full	17.4	0.4	17.6	41.1	Salmasi	Full	16.5	3.7	16.4	39.8
	Half	82.6	99.6	82.4	58.9		Half	83.5	96.3	83.6	60.2
	Zero	-	-	-	-		Zero	-	-	-	-
Hariri	Full	14.5	1.0	15.9	48.8	Alavi	Full	22.5	1.3	21.8	61.8
	Half	85.5	99.0	84.1	51.2		Half	77.5	98.7	78.2	38.2
	Zero	-	-	-	-		Zero	-	-	-	-
Heydar.	Full	31.2	2.2	30.3	93.8	Gadaki	Full	18.3	1.1	18.1	47.1
	Half	68.8	97.8	69.7	6.2		Half	81.7	98.9	81.9	52.9
	Zero	-	-	-	-		Zero	-	-	-	-
Khatayi	Full	36.8	1.1	39.5	68.5	Mashroteh	Full	24.7	-	21.9	70.1
	Half	63.2	88.3	64.1	31.5		Half	75.3	100	78.1	29.9
	Zero	-	10.6	-	-		Zero	-	-	-	-

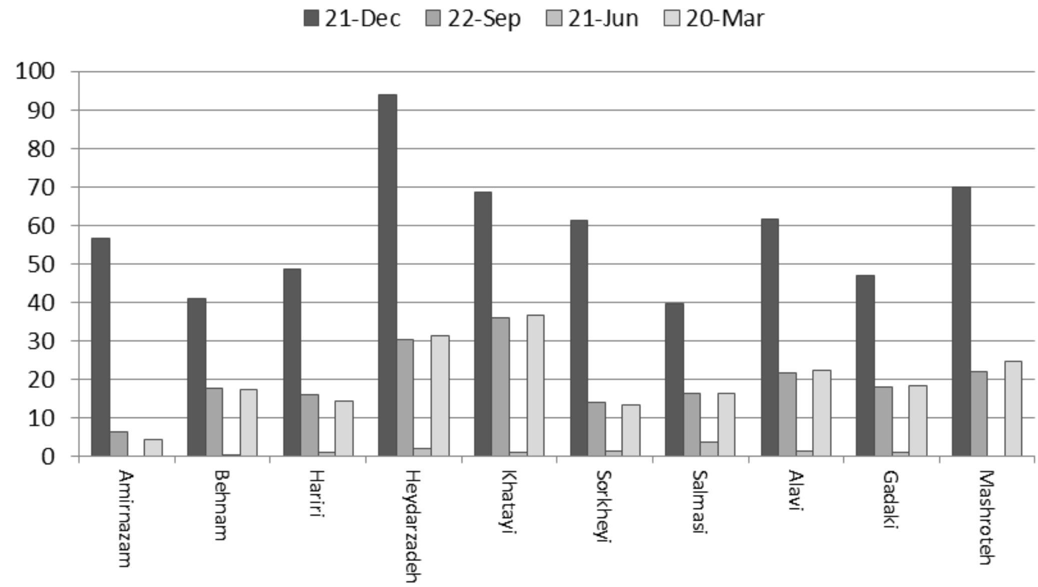


Figure 13. Graph of sunlight and shade hours in the selected courtyards of Tabriz traditional houses

The sum of sky viewing angles in section and facade equals the “sky mask”, which is plotted on the shading protractor using the Olgyay shading mask method. By adapting the sun movement way of each city, the area of the observable sky from the windows center can be obtained. For instance, Table 12 shows hot to calculate the sky mask percentage in the window of room 2 of Behnam traditional House in Tabriz.

Table 12. Example of sky mask analysis in selected spaces of House (Room No. 2, Behnam traditional house)

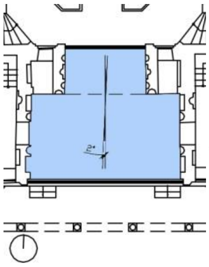
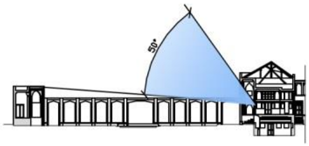
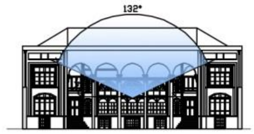
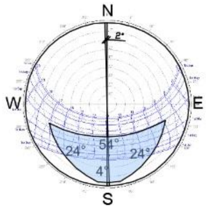
Room	Window direction	Window Position in plan	Visible Sky angles in section	Visible Sky angles in facade	Percentage of sky mask
2	South		 50°	 132°	 %18

Table 13. Sample data collection of physical elements of rooms in Tabtiz selected Houses (Behnam traditional house)

Room	North	South	Eest	West	B (m)	A (m)	H_R (m)	A_R (m^2)	A_W (m^2)	B/ A	B/ H_R	A/ H_R	A_W/ A_R	A_R/ Acy (%)
1		■			3.6	8.4	3.0	29.9	10.8	0.43	1.20	2.80	0.36	3.6
2		■			8.0	6.6	4.2	42.4	33.6	1.21	1.90	1.57	0.79	5.1
3		■			3.6	8.3	3.0	30.4	10.8	0.43	1.20	2.76	0.35	3.7
4	■				8.0	6.6	4.2	42.4	33.6	1.21	0.90	1.57	0.79	46.4
5			■		5.5	3.3	3.0	17.8	16.5	1.66	1.83	1.10	0.93	19.5
6				■	5.4	6.0	3.0	25.2	16.2	0.90	1.80	2.00	0.64	27.6

Table 14. Sample data collection of physical elements of windows in Tabtiz selected Houses (Behnam traditional house)

Room	Sash	French	Pachang	Simple	Rozan	Material	Out Wall	In Wall	W (m)	H (m)	okb (m)	A_{Wi} (m^2)	A_W (m^2)	A_R (m^2)	A_{Wi}/ A_W (%)	A_{Wi}/ A_R (%)
1	-	-	-	1	-	Wood	■	-	2.5	2.6	0.00	6.50	10.8	29.9	60.2	21.7
2	1	-	-	-	-	Wood	■	-	8.0	4.0	0.00	32.0	33.6	42.4	95.2	75.4
3	-	-	-	1	-	Wood	■	-	2.5	2.6	0.00	6.50	10.8	30.4	60.2	21.3
4	1	-	-	-	-	Wood	■	-	4.1	3.9	0.00	16.0	33.6	42.4	47.6	37.7
5	-	3	-	-	-	Wood	■	-	1.1	2.0	0.00	6.60	16.5	17.8	40.0	37.0
6	-	3	-	-	-	Wood	■	-	1.1	2.0	0.00	6.60	16.2	25.2	40.7	26.1

2.5. Analysis of the number of sunlight hours in the windows of the chosen rooms and determination of high-quality rooms

Given the importance of sunlight in improving the quality and health of spaces, various standards have made some suggestions for taking advantage of direct daylight. The minimum number of sunlight hours in at least one space of the building which is toward the sun during a day or a particular period is recommended.

The sunlight hour analysis engine in the Ecotect software was used to evaluate the number of sunlight hours. For instance, Table 15 shows the analysis of sunlight hours in the windows of room 2, 5 and 6 of Behnam traditional House in Tabriz.

By analyzing the information of the chosen rooms using the related software programs and daylight standards, among the 48 rooms, 10 rooms did not receive the minimums required for the proper daylight quality and number of sunlight hours while the other 38 ones had proper daylight quality.

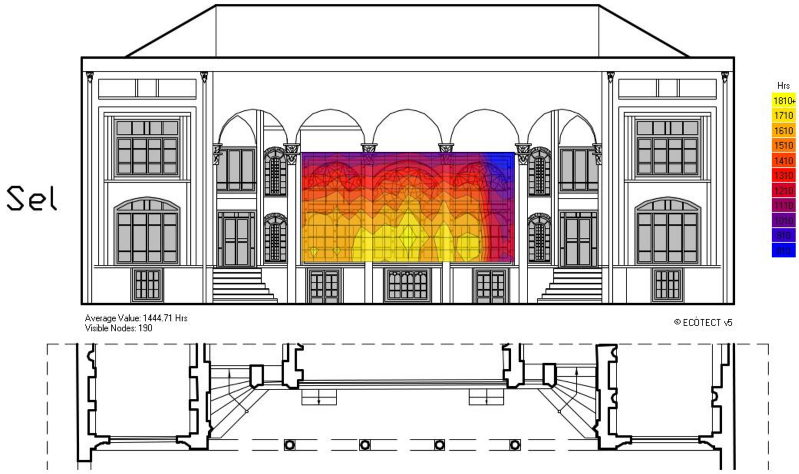
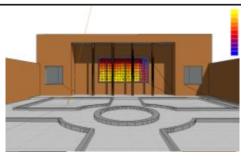
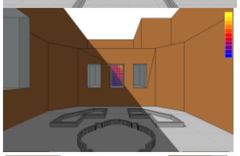
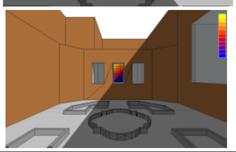


Figure 14. Sample analysis of sunlight in the windows of selected rooms (Room No. 2, Behnam traditional house)

Table 15. Check the quality of sunlight hours in the windows of selected rooms (Behnam traditional house)

Room	Sunny Window	Day Period	SHW	SHC	SHW/ SHC (%)	Grade	L (m)	A (m)	Room Index	Visible sky in room
2		1 Feb.	8.50	9.00	94	3	9.14	6.6	100%	100%
		21 Mar.	8.00	10.0	80	3				
		All year	1710	3540	48	3				
		Winter	1410	1710	82	3				
5		1 Feb.	0.00	9.00	0	0	3.94	3.3	100%	100%
		21 Mar.	1.00	10.0	10	0				
		All year	540	3540	15	1				
		Winter	8.00	1710	0.5	1				
6		1 Feb.	0.00	9.00	0	0	3.92	6.0	65.3%	100%
		21 Mar.	4.00	10.0	44	3				
		All year	1020	3540	29	3				
		Winter	42.0	1710	2.5	1				

2.6. Evaluation of the correlation between the elements of windows and rooms in spaces with the daylight quality and number of sunlight hours

The bivariate Pearson correlation was used to discover a logical relationship between the elements of windows and rooms. 1) The correlation between width, depth, and height of room, 2) The correlation between width and length of windows, and 3) The correlation between the yard area, room area, area of the wall containing windows, and window area, were separately evaluated.

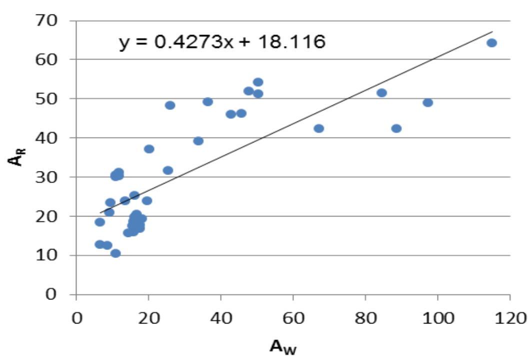


Figure 15. Sample chart between room elements in selected rooms of Tabriz Houses (A_R/A_W)

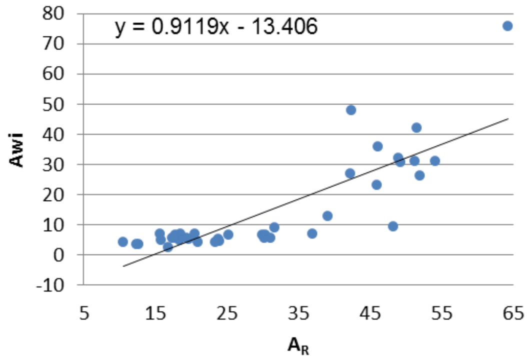


Figure 16. Sample chart between window elements in selected rooms of Tabriz Houses (Awi/A_R)

3. Results & Discussion

By comparing the studies performed on the daylight quality in traditional buildings of Iran and the study conducted in this regard, it can be concluded that:

1. The physical elements of open space (yard) have particular relationships, and the most significance is observed between the length and width of the yard. The pattern suggested for the houses in the hot and dry region [54-56] and the historical houses of Ardabil [57] have been provided in the past studies.

2. The physical elements of the closed space (room and windows) in most major spaces of the traditional buildings of Qajar era had the minimums required for receiving proper daylight in the space [11, 13, 14]. However, no pattern has been provided in this regard. In this study, significant relationships were obtained between the elements of the room and window in the spaces of rooms with daylight quality and number of sunshine hours.

Among the 38 evaluated rooms of the traditional houses of Tabriz, which have the minimum daylight quality, 17 room are toward the south, 2 ones are toward the north, 10 ones are toward the east, 4 ones are toward the west, and five ones have northern-southern rooms. Among these spaces, except for two rooms toward the north, the spaces have the minimum quality of sunshine hours.

A linear relationship between the elements of spaces with daylight quality and proper sunshine hours is defined using the correlation equations between the elements. Logical relationships with high correlation coefficient is determined, and the correlation equation between their elements are as shown in Table 16.

4. Conclusions

The evaluation of the open and closed spaces of the historical buildings of Qajar era indicates that in most studied spaces of these buildings, the daylight quality and number of sunshine hours based on the daylight standards have favorable values. The study results indicate a logical relationship between some elements of the windows and rooms in closed spaces associated with the windows guaranteeing proper daylight. According to Table 17, by evaluating the physical elements of all chosen 38 rooms with proper daylight in the houses of Tabriz, the patterns of the suggested plan with the highest correlation between them is proposed. These suggested patterns can provide a solution for designing rooms and windows in the buildings of the city and cold and dry climate of Iran.

City	Room direction	Nomber	Correlation	B-A	Grade	B-H_R	Grade	A-H_R	Grade	A_R-Acy	Grade	A_W-A_R	Grade	Bw-Hw	Grade	Bw-B	Grade	Bw-A	Grade	Hw-H_R	Grade	Awi-Aw	Grade	Awi-A_R	Grade	X of 33
Tabriz	S	17	P-Value	0.351	0	0.025	1	0.267	0	0.231	0	0.000	3	0.031	1	0.000	3	0.687	0	0.001	3	0.000	3	0.000	3	17
			r	0.241	0	0.539	2	0.285	0	0.307	1	0.881	3	0.523	2	0.944	3	0.105	0	0.700	3	0.925	3	0.895	3	20
			Relation.	X		✓		X		X		✓		✓		✓		X		✓		✓		✓		
	N	2	P-Value																							
			r																							
			Relation																							
	E	10	P-Value	0.833	0	0.721	0	0.228	0	0.287	0	0.012	2	0.644	0	0.001	3	0.823	0	0.001	3	0.001	3	0.007	2	13
			r	0.076	0	0.129	0	0.418	1	0.373	1	0.751	3	0.167	0	0.875	3	0.081	0	0.867	3	0.865	3	0.783	3	17
			Relation	X		X		X		X		✓		X		✓		X		✓		✓		✓		
	W	4	P-Value	0.556	0	0.124	0	0.722	0	0.071	0	0.039	1	0.056	0	0.046	1	0.455	0	0.154	0	0.022	1	0.085	0	3
			r	0.444	1	0.875	3	0.277	0	0.929	3	0.960	3	0.943	3	0.954	3	0.544	2	0.845	3	0.977	3	0.914	3	27
			Relation	X		✓		X		✓		✓		✓		✓		X		✓		✓		✓		
	SN	5	P-Value	0.438	0	0.995	0	0.128	0	0.756	0	0.079	0	0.864	0	0.027	1	0.478	0	0.567	0	0.407	0	0.089	0	1
			r	0.457	1	0.003	0	0.769	3	0.192	0	0.834	3	0.106	0	0.918	3	0.422	1	0.346	1	0.485	1	0.820	3	16
			Relation	X		X		✓		X		✓		X		✓		X		X		X		✓		
	EW	0	P-Value																							
			r																							
			Relation																							
All Room		38	P-Value	0.695	0	0.000	3	0.714	0	0.074	0	0.000	3	0.000	3	0.000	1	0.495	0	0.000	3	0.000	3	0.000	3	19
			r	0.065	0	0.560	2	0.061	0	0.292	0	0.799	3	0.598	2	0.855	3	0.114	0	0.746	3	0.910	3	0.829	3	19
			Relation	X		✓		X		X		✓		✓		✓		X		✓		✓		✓		

Figure 17. Analysis of logical relationships and correlations between room and window components in spaces with daylight standards in Tabriz houses

Table 16. Correlation equation between the elements of room and window in rooms with daylight quality suitable in Tabriz selected traditional houses

City	Room Nomber	Elements	r	P-Value	Correlation Equation
Tabriz	38	B, H_R	0.560	0.000	$H_R = 0.22 B + 2.61$
		Aw, A_R	0.799	0.000	$A_R = 0.43 Aw + 18.12$
		Bw, Hw	0.598	0.000	$Bw = 2.35 Hw - 4.42$
		Bw, B	0.855	0.000	$Bw = 1.30 B - 2.91$
		Hw, H_R	0.746	0.000	$Hw = 0.55 H_R + 0.67$
		Awi, Aw	0.910	0.000	$Awi = 0.53 Aw - 1.25$
		Awi, A_R	0.829	0.000	$Awi = 0.91 A_R - 13.41$

Table 17. Proposed patterns for designing rooms and windows in Tabriz buildings and the cold region of Iran

Elements of Room and Window	Correlation Equation
Awi, Aw	$Awi = 0.53 Aw - 1.25$
Bw, B	$Bw = 1.30 B - 2.91$
Awi, A_R	$Awi = 0.91 A_R - 13.41$
Aw, A_R	$A_R = 0.43 Aw + 18.12$
Hw, H_R	$Hw = 0.55 H_R + 0.67$

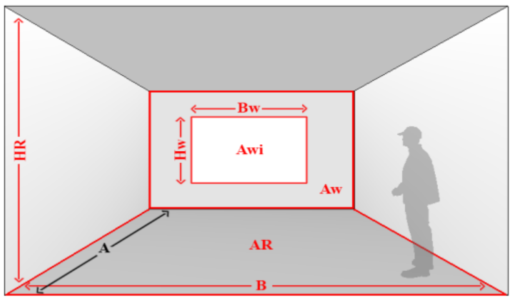


Figure 18. Highest correlation between closed space elements

Nomenclature

SL	Sunlight
Atotal	Total Area
ATel	Total Elevation Area
Aos	Open Space Area

Acs	Close Space Area
NW	Northwest
Sel	South Elavation
Nel	North Elavation
Eel	East Elavation
Wel	West Elavation
ASel	South Elavation Area
ANel	North Elavation Area
AEel	East Elavation Area
AWel	West Elavation Area
AOSel	Openings Area in South Elavation
AONel	Openings Area in North Elavation
AOEel	Openings Area in East Elavation
AOWel	Openings Area in West Elavation
Lcy	Courtyad Length
Wcy	Courtyad Width
Acy	Courtyad Area
A_R	Room Area
H_R	Room Heigth
A	Room Depth
B	Room Width
Aw	Wall Area
Awi	Windows Area
Hw	Window Heigth
Bw	Window Width
SHW	Sunlight hours in Window
SHC	Sunlight hours in City
L	Depth of daylight Illuminance
Room Index	L to A Ratio
r	Correlation Coefficient

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