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Impact of Building Orientation on Annual Energy Consumption in Schools in Hot Arid Regions in Iran, Using Climate Modeling, Case Study: A Double-class School*

Hamid Aibaghi Esfahani[a]- Kourosh Momeni[b]- Faramarz Hassan Pour[c]**

[a] Department of Architecture, Zahedan Branch, Islamic Azad University, Zahedan, Iran.

[b] Associate Professor of Architecture, Department of Architecture, Faculty of Architecture and Urban Planning, Jundi-Shapur University of Technology, Dezful, Iran (Corresponding Author).

[c] Assistant Professor of Architecture, Department of Architecture, University of Zabol, Zabol, Iran.

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ABSTRACT

School buildings constitute a large part of the public buildings and thereby being the most important consumers of energy in Iran. Considering the current construction conditions, reforming construction and design methods seems to provide a lot of potential for energy efficiency. Considering a large number of schools in Iran, it is of special importance to carefully study such methods, one of which is to modify building geometry factors, including building orientation. In this study, a double-class school with a simple plan, as a typical building pattern in hot arid regions of Iran, is considered as a case study to accurately determine its optimal orientation for six cities of Isfahan, Shiraz, Zahedan, Qom, Kerman, and Yazd, as cities with over 500,000 people in the hot arid regions of Iran, using computer simulation. To this end, for each city, 72 models are simulated in different directions with a 5-degree variance, and a 10-degree range of the minimum annual energy consumption is obtained. Next, the simulation with a 1-degree variance is performed in the same range, and the results obtained for the six cities are compared. Finally, for this building type, the greatest and smallest impact of the building orientation on energy consumption is observed in Qom city and Yazd city, respectively. Also, despite the low percentage of annual energy savings, due to a large number of typical buildings in all six cities and their useful life span of 50 years, it is necessary to carefully choose the direction for the long period. Because the small amount of fuel storage during the annual consumption of a building will become a significant number at the national level during the entire period of operation.

Keywords: Building Orientation, Double-Class School, Hot Arid Climate, Energy Efficiency, Climate Modeling.

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** E_mail: k_momeni@jsu.ac.ir

1. INTRODUCTION

According to the International Energy Agency (IEA) (2013), buildings are responsible for one-third of all the energy consumption and one-third of the total carbon dioxide emissions. De Wilde and Coley (2012) have reported buildings to account for 25 to 40 percent of greenhouse gas emissions. Buildings are usually intended to be used for 60 to 80 and sometimes up to 100 years, so it is of great importance to consider energy efficiency in the design phase (Laustsen, 2008, p. 7). The average energy consumption in the Iranian school buildings, as a major category of public buildings, is more than 160 KWh/m^2 (Iranian Fuel Conservation Organization, 2009). This is 2.5 times the energy annually consumed in schools in developed countries with an approximate amount of 65 KWh/m^2 (Im & Habrel, 2006). Despite the high energy consumption, thermal comfort may not be still provided in many classrooms. Although schools in hot arid regions account for 41.9% of the total energy consumed by schools in Iran, there is still no specific code for the construction of schools to reduce energy consumption (Joshghani, 2001).

Engineers and researchers have been using computers to simulate the building construction processes for more than four decades (Oberkampf & Trucano, 2002). What makes using the Building Energy Simulation (BES) Software necessary is that it allows examining the features of the building before the construction phase to reduce energy consumption.

Moreover, one of the important factors significantly influencing energy consumption is the architectural design and its various parameters including geometric form, window-to-wall ratio, sunshade size and direction, building orientation, etc. Proper use of geometric parameters of buildings, rooms, openings, and other openings-related elements, such as sunshades and glasses significantly reduces energy consumption in the building and improves the energy-saving performance (Susorova, Tabibzadeh, Rahman, Clack, & Elnimeiri, 2013).

Among the factors above-mentioned, choosing the optimal building orientation is very low cost and can be done only using survey cameras in the initial stage of construction. In the past, the building orientation was generally selected considering the impact of landscape, prevailing winds, topography, adjacent buildings, etc., and in some cases, the existing conditions of urban design such as historical texture or other influential factors. It is less possible to select a proper building orientation considering the prevailing winds to provide better cross-ventilation in the building or constructing the building with a certain orientation to use the sun's energy for the heating during the winter months, often for the reasons abovementioned. While in rural areas, there are fewer such limitations.

A proper building orientation allows natural ventilation, absorption of sunlight, absorption of the sun's heat during the cold months, and reduced absorption of the sun's heat during the hot months. Therefore, it is helpful to find the optimal building orientation to reduce the energy annually consumed in the building. In the present study, the Design-Builder software was used to prove this hypothesis. This software enables the user to quickly combine various models and provide advanced energy simulation.

Many researchers have studied the building geometry factors, including building orientation and its relationship with energy consumption. However, there has been little focus on the building orientation or most studies have investigated it with low accuracy and up to 15 degrees, as discussed in more detail in the literature review.

In the present study, using the computer simulation of a double-class school, as a typical pattern in the most populous hot arid cities of Iran, in different directions, and analyzing the data, it was attempted to answer the following questions:

1. To what extent does the building orientation of the double-class schools influence the annual energy consumption in each of the studied cities?
2. In each of the cities studied, what building orientation best serves energy efficiency in the case of double-class schools?
3. Given the various issues, including the useful life span of these buildings and a large number of typical buildings, how important is it to accurately determine the proper building orientation?

In the present study, there are two variables: building orientation, as an independent variable, and annual energy consumption, as a dependent variable.

2. LITERATURE REVIEW

Most studies examining the impact of architectural factors on energy consumption in buildings have evaluated the building orientation less accurately. The following are some of them:

In their study, through building simulation, Vasaturo et al. (2018) have investigated four main cardinal directions and four sub-directions, i.e. a total of eight directions of north, south, east, west, northwest, northeast, southwest, and southeast to study the impact of building orientation on the energy demand of a detached lightweight semi-portable building for cooling and heating. Finally, different orientations, as optimal orientations, have been proposed for different climates.

Considering the determination of the optimal building orientation as a cheap way for energy efficiency, Morrissey et al. (2011) have selected 81 examples of residential plans and measured their energy consumption in different orientations by modeling them in AccuRate Software. Since many parameters have been studied in this study, various results have been obtained for the optimal orientation by changing parameters and a clear single result has not been reported for it. However, the northeast-southeast orientation has been more confirmed.

Da Graça et al. (2007) have categorized different types of school building plans in Sao Paulo, Brazil, and provided a method for evaluating and optimizing various school building parameters according to four different aspects of comfort: thermal, acoustic, natural lighting, and functionality. The results showed it is not possible to simultaneously optimize all the above-mentioned aspects of comfort. However, some adaptations were observed. They have also provided a table representing various orientations, as the optimal building orientation, for different plans according to different parameters.

In the abovementioned studies, the orientation variable has been studied only in the eight main directions and sub-directions abovementioned.

Zomorodian and Nasrollahi (2013) have studied the architectural parameters of school buildings in the hot arid regions of Iran, including a series of geometry factors such as building form, spatial organization, and window-to-wall ratio, and have tried to provide some solutions for reducing energy demand by making appropriate changes in the parameters through computer simulation. Finally, the energy demand of the studied school has been reduced by up to 31% only by changing the architectural parameters and making no changes in the type of building materials and structural parameters. In this study, the building orientation factor has been investigated with an accuracy of 10 degrees east-west orientation has been proposed as the optimal orientation for the studied building with a south-facing entrance.

Pathriana et al. (2019) has rotated the building by 15 degrees to determine the optimal orientation of a house in the tropical climate to achieves the least hours of thermal discomfort and the least need for electric lighting throughout the year. 24 models were obtained. In this study, according to the plans, climate studied, and other parameters, authors have considered the problem of building orientation to be negligible and have reported no optimal orientation.

Zhang et al. (2017) have applied a genetic algorithm to optimize the thermal and daylight performance of school buildings in the cold climate of China. They have compared and simulated three plans with different windows and sunshades, different depths for corridors and rooms, etc. The results indicated the school with a two-way corridor has the best thermal and daylight performance in this climate. Other related parameters have been proposed and according to each parameter, different optimal orientations have been obtained for different climates. In this study, since Rhino software and Grasshopper and Octopus plugins have been used for parametric analysis, to investigate the building orientation, the accuracy ranged from 0 to 360 degrees, while only the cold climate of China has been studied.

In the abovementioned studies and many other studies, researchers have not investigated the building orientations of schools independently or studied them with an accuracy of about 10 to 15 degrees. They have usually examined all the geometry and architectural factors of the building together. In the present study, it was attempted to investigate this geometry factor in the building independently and with high accuracy.

3. GENERAL CONSIDERATIONS

In the hot arid climate, energy efficiency is of special importance due to unfavorable weather conditions, the very large temperature difference between day and night, strong sunlight, etc. In Iran, deserts and semi-deserts occupy a large part of its territory. Researchers have analyzed various factors to determine deserts in Iran, including climate, geomorphology, geology, pedology, hydrology, and vegetation (Shabankareh, Khosrowshahi, & Qolampour, 2008). The survey of Iran indicates the total area of lands considered desert at least based on one of the aforementioned factors is 985798 km^2, accounting for 59.8% of the total area of Iran (Khosrowshahi & Kalirad, 2013, p. 27). This highlights the importance of research in this type of climate.

What makes the issue of population important in choosing the cities is the need to build schools in the coming years in more populated areas. The studied cities are located in the hot arid regions of Iran and all have a population of above 500,000 people (Iran's Statistical Yearbook, 2016; 2018, p. 148).

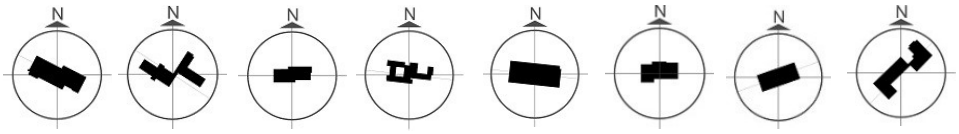
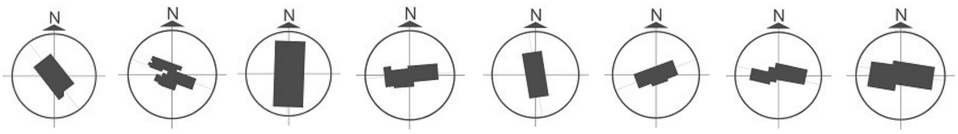
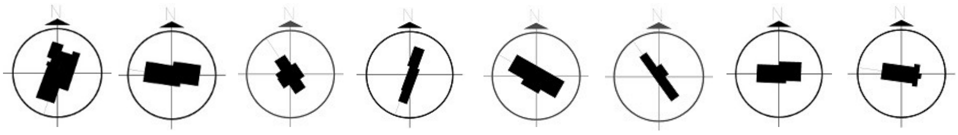
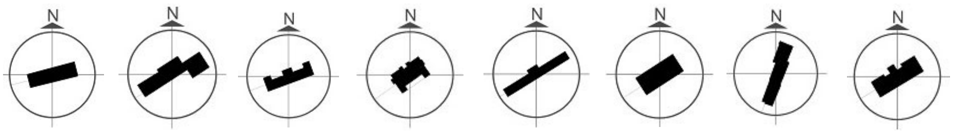
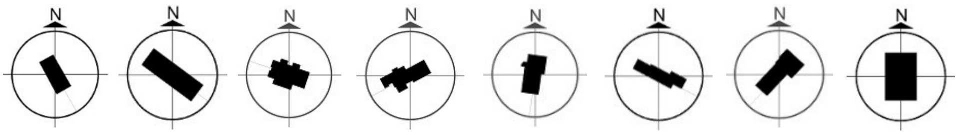
3.1. The Prevalent Building Orientation of Schools in the Studied Cities

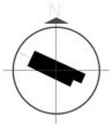
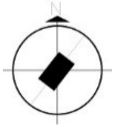
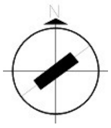
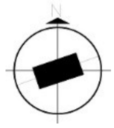
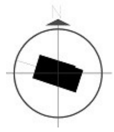
To evaluate how much optimal orientation influences the annual energy savings, first it was attempted to find the prevalent orientation in these six cities to calculate the following formula:

$$\text{(\%) Impact of Optimal Orientation on Annual Energy Efficiency} = 100 \times \frac{\left(\text{Annual Energy Consumption in the Prevalent Orientation}\right) - \left(\text{Minimum Annual Energy Consumption}\right)}{\left(\text{Minimum Annual Energy Consumption}\right)}$$

To this end, 20 to 30 double-class schools built in each city were examined. Table 1 shows 8 examples for each city.

Table 1. Investigation and Analysis of the Prevalent Orientation of the Schools in the Six Cities Studied

City		1	2	3	4	5	6	7	8	Prevalent Orientation in the City
Isfahan	School Name	Bahar-e Azadi High School	Harati High School	Monir High School	Mostafa Khomeini High School	Nilforoush zadeh High School	Venus High School	Sadat High School	Nezam al-Islam High School	Unknown The Isfahani Ron is not Followed.
	Orientation (°)	117-297	123-303	90-270	96-276	96-276	90-270	69-249	46-226	
	Figure									
Zahedan	School Name	Alame Helli High School	Daneshgah High School for Boys	Daneshga High School for Girls	Imam Mosa Kazem (AS) High School	Motahareh High School	Velayat High School	Fatemiyeh High School	Shahed High School (2)	Unknown
	Orientation (°)	143-323	110-290	3-183	86-266	171-351	69-249	102-282	99-279	
	Figure									
Shiraz	School Name	Zand High School for Girls	Hazrat Masoumeh High School	Tohid High School	Be'esat Elementary School for Girls	Bagher al-Oloum High School	Abozar High School	Khorasanian High School	Dr.Hesabi High School for Girls	Unknown
	Orientation (°)	19-199	98-278	146-326	20-200	120-300	144-324	92-272	98-278	
	Figure									
Kerman	School Name	Imam Mahdi (AS) High School	Ahmadi Roshan High School	Hesabi High School	Helli High School (2)	Shahed High School for Boys	Fatemiyeh High School	Seyyed Kamal Mousavi High School	Shariati High School	Northeast to Southwest
	Orientation (°)	76-256	57-237	70-250	55-235	58-238	57-237	20-200	59-239	
	Figure									
Yazd	School Name	Shahed High School	Ayat High School for Boys	Jeyhoun High School	Khalili High School for Girls	Meshkan High School for Girls	Mashahir Azam High School	Shahid Sadough High School	Imam Hussain (AS) High School for boys	Unknown (Rasteh Ron is followed)
	Orientation (°)	150-330	127-307	109-289	62-242	8-188	118-298	43-223	0-180	
	Figure									

City		1	2	3	4	5	6	7	8	Prevalent Orientation in the City
Qom	School Name	17 Shahrivar High School	Khadivi High School for Girls	Shahid Sadr High School	Shahid Zeyn al-Din High School	Shahid Jadda High School for Boys	Shahid Javad Borghehei High School	Farzanegan High School (2)	Imam Sadegh (AS) High School	Unknown
	Orientation (°)	116-296	38-142	54-126	126-306	20-20	107-287	96-276	97-274	
	Figure									

It was found that in the current situation, only for Kerman City, a prevalent orientation can be considered for the schools, and in other cities, there is no prevalent orientation and the traditional orientation (called Ron in the Iranian architecture) is not followed. Therefore, in the abovementioned formula, for all cities except for Kerman, the maximum annual energy consumption (related to the most unsuitable orientation) should be substituted for the first term in the numerator. It seems that in urban areas, there are limitations in choosing the building orientation, such as the situation of the surrounding streets, while in rural areas, the building orientation can be determined very accurately since there are no such limitations.

3.2. Simulation Software

In the present study, Design Builder software was used to calculate the annual energy consumption. This software allows analyzing the energy and thermal load of the building and simulating the heating, cooling, lighting, ventilation, and water consumption models for the building. This software is a graphical user interface and uses the Energy Plus engine. Energy Plus is a well-known energy simulation engine that has been developed and sponsored since 1996 by the United States Department of Energy (DOE) (Simulation and Energy Plus, 2012; Crawley, Lawrie, Winkelmann, Buhl, Huang, Pedersen, Strand, Liesen, Fisher, Witte, & Glazer, 2001; Crawley, Hand, Kummert, & Griffith, 2008).

3.3. Climate and Location

Various climate classifications have been proposed in the world one of which is the Köppen climate classification proposed by Wladimir Köppen (1846-1940), a Russian scientist, in 1884. This classification includes five climate zones based on the vegetation on a global scale. Various climate zones have been also proposed for Iran, the most well-known of which includes 4 climate zones: 1. 1) Temperate and humid climate (the southern coastline of Caspian Sea); 2) cold climate (western mountains); 3) arid and hot climate (the Central Plateau); and 4) hot and humid climate (southern coasts) (Kasmaee, 2003, p.82). The cities studied in the present study are located in the arid region of Iran. Moreover, with a population ranging from 529,000 to 1,900,000 people, they are the most populous hot arid cities in Iran. Table 2 shows the longitudes, latitudes, altitudes, and population of these cities.

Table 2. General Characteristics of the Studied Cities

City	Latitude	Longitude	Altitude (m)	Population (in 2016) (People)
Isfahan	32°31´3" E	51°42´22" N	1550	1961260
Zahedan	60°54´1" E	29°28´20" N	1370	587730
Shiraz	52°36´9" E	29°33´41" N	1488	1565572
Qom	53°51´19" E	34°46´29" N	879.1	1201158
Kerman	56°57´45" E	30°15´22" N	1754	537718
Yazd	48°31´23" E	36°39´37" N	1230.2	529673

(Iran's Statistical Yearbook, 2018)

3.4. Meteorological Data

The outdoor hourly weather data is used as one of the most important parameters to explain the interior temperature and the energy required for thermal comfort. The United States Department of Energy (DOE) freely provides weather data for more than 2,100 regions of the world, including six cities of Bandar Abbas, Tehran, Tabriz, Shiraz, Isfahan, and Yazd in Iran, in epw and ITMY formats. For this study, the hourly weather files of Yazd, Shiraz, and Isfahan were freely downloaded in ITMY format from the Energy Plus website[1].

To prepare the hourly weather file for Zahedan, Kerman, and Qom cities in epw format (which are not available on Energy Plus website), the data measured in the period from 1997 to 2017 by the Iranian Meteorological Organization were used. The data provided by the Iranian Meteorological organization are available for every three hours. So, to prepare epw files, it is necessary to prepare hourly data after selecting the required months in a given year. To this end, the Lagrange interpolation formula was used for the three reported data to obtain the unreported data related to every two hours.

Table 3. List of Data for Lagrange Interpolation

Hours (from the First Day)	Parameter Value	Hours	Parameter Value	Hours	Parameter Value
1	F1	5	F5	9	F9
2	F2	6	**F6**	10	**F10**
3	**F3**	7	F7	11	**F11**
4	F4	8	F8	12	F12

To this end, first, all available data (bolded data in Table 3) were listed in a table in an hourly order (from 1 to 8760). Next, the missing data (non-bolded data in Table 3) were calculated from the three available data using the Lagrange interpolation formula. For example, to determine the values of F4 and F5 data, the F3, F6 and F9 data were interpolated, or to find the values of F7 and F8 data, the F6, F9, and F12 data were interpolated. Similarly, all the missing data were calculated for the whole year and to find the values of F7 and F8 data, the F3, F6, and F8760 data were interpolated. The Lagrange interpolation formula for the three data is as follows:

Table 4. Data Adaptation in Lagrange Interpolation

X	X_0	X_1	X_2
F	F_0	F_1	F_2

$$p(x) = L_0F_0 + L_1F_1 + L_2F_2$$

$$L_0(x) = \frac{(x-x_1)(x-x_2)}{(x_0-x_1)(x_0-x_2)}, \quad L_1(x) = \frac{(x-x_0)(x-x_2)}{(x_1-x_0)(x_1-x_2)} \quad , \quad L_2(x) = \frac{(x-x_0)(x-x_1)}{(x_2-x_0)(x_2-x_1)}$$

3.5. Case Studies

For this study, the selected plan can be easily constructed in remote hot arid villages using minimal human forces and materials. A great number of schools with the same plan were built in hot arid regions of Iran. For example, in Sistan and Baluchistan Province, as one of the vast hot arid region in Iran, there are 439 schools with the same plan[2].

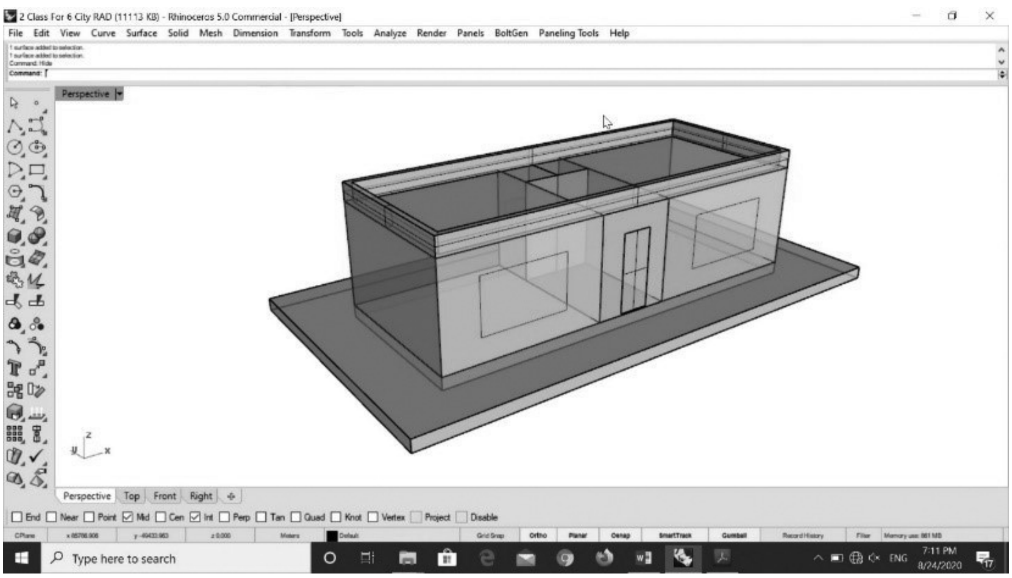


Fig. 1. Rhino Model, Based on the Sample Building Built In Sistan and Baluchistan, Iran-E Man School No. 5, Khajeh Mask Village, Zahedan

Due to the large number of schools built and being built with this plan, it is of great importance to save the annual energy in a building, even as many as a few kilowatts per hours, because on the scale of the entire hot arid regions of Iran, the large number of buildings will result in significant energy savings, significantly reducing carbon dioxide emissions.
The study building is a double-class one-storey school with a total area of 72.36 m^2. It composed of two classrooms each with an area of 23.50 m^2, a teacher office of 7.80 m^2, and two bathrooms each with an area of 1.3 m2. The remaining area of the building is related to the wall thickness. The distance between the floor and the top of the roof is 340 cm and the window- to-wall (WWR) in the classrooms is 18% considering the east-west orientation on the north and south sides. The eastern and western walls of the classrooms have no windows. All doors and windows have no sunshades.

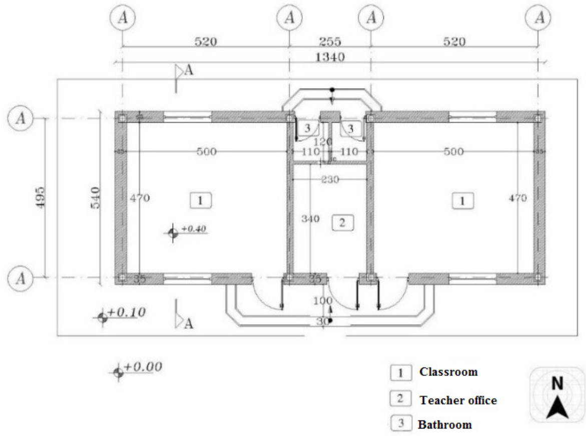


Fig. 2. Ground Floor Plan
(Archive of School Renovation Organization Documents)

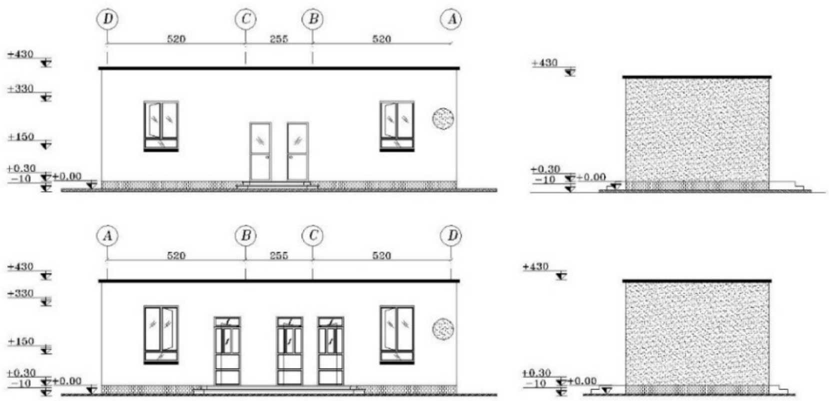


Fig. 3. Facades
(Archive of School Renovation Organization Documents)

Table 5 presents information on the occupancy density, fresh air supply rate, and equipment densities according to ASHRAE[3] standard for different spaces in the building (ASHRAE, 2007; 2009).

Table 5. Zones and Related Information

Zone	Flor area (m^2)	Zone volume (m^3)	Occupancy (people/m^2)	Lighting (lux)	Equipment (w/m^2)	Fresh Air (L/s-person)
Classroom 1	23.5	72.25	0.875	300	4.70	5.5
Classroom 2	23.5	75.12	0.875	300	4.70	5.5
Teacher office	7.8	24.65	0.23	200	18.54	10
WC 1	1.29	3.98	0.1124	150	5.48	12
WC 2	1.29	3.98	0.1124	150	5.48	12

3.5.1. Building Components

The plans, details, materials of walls, roofs and other building components were provided by the Organization for Development, Renovation and Equipping of Schools (DRES) of Iran. Since, in the current conditions for the implementation of this plan, thermal insulation is not used in the ceiling layers and walls, the actual conditions and materials were considered in the present study. Because this study aimed to compare the building orientation models. In fact, optimization of the wall materials, ceiling insulations, structural layers used in the ceiling, the window-to-wall ratio, window-sill height, window orientation, classroom depth, optimal length of sunshades, etc. can be the subjects of future studies. Table 6 shows the layers of materials used in walls, ceilings and window panes of the models and the U-Value calculated for them.

Table 6. Layers of Materials Used in the Models

Section	U-Value W/(m^2k)
External Walls: Brickwork, Outer Leaf (30mm) Mortar (10 mm) Brick (225 mm) Gypsum Plastering (20mm)	1.725
Internal Partitions: Gypsum Plasterboard(25 mm) Air Gap (100mm) Gypsum Plasterboard (25 mm)	1.639
Roof: Asphalt (20mm) Mortar (10mm) Bitumen/Felt Layers (10mm) Mortar (10mm) Mineral Fibre (100 mm) Cast Concrete (250mm) Mortar (10mm) Gypsum Plastering (10mm)	0.570
Glazing: Generic BLUE (6mm) AIR (13mm) Generic CLEAR (6mm)	2.665

The calculated u-value for it is 0.57(W/m2-K). Insulated glazing with a thickness of 6 mm was used in the building with a 13-mm intermediary air layer. Their U-value is 2.785 (W/m^2-K) and their Solar Heat Gain Coefficient (SHGC) is 0.497. Table 9 shows the properties of the insulated glazing. The window frames are made of aluminum plates with a thickness of 2 mm, in the middle layer of which a polyvinyl chloride (PVC) layer with a thickness of 5 mm is used as a thermal break. The U-value of this window frame is 4.719(W/m^2-K). In the present study, according to previous research, the lighting required in the classrooms is at least 300 lux at a height of 80 cm from the floor and the lighting required for the teacher office and bathrooms is 200 lux, and 150 lux[4], respectively (Mahlabani et al., 2011). (Mahlabani, Faizi, & Khakzand, 2011; Rea, 2000). Table 5 shows the lighting density required for different rooms in lux. LED lights with linear control were used to meet the lighting shortage at hours when there is little daylight or the weather is cloudy. The radiation fraction[5] of the lights is 0.37 and their visible fraction[6] is 0.18. The normalized power density is also 2.5 (W/m^2-100 lux). The linear lighting control was considered for the lights and the radiation was automatically adjusted to only compensate for the lighting shortage relative to daylight. The properties of the abovementioned lights are listed in Table 10.

Table 11 shows the thermal properties of the exterior walls, ceiling, and window frames used in the models. Of course, the optimum properties of the glazing, window profiles, and the sunshade size and form required for the maximum annual energy efficiency are the subjects of future research

3.6. Simulation Parameters

The settings required in the Design Builder software to perform required calculations are including the precise definition of building components, building use schedule, climate file in (epw) or (ITMY) format according to the hourly weather data of each region, HVAC systems and their schedule, the type of activity performed in each Zone and its daily occupancy, the heating and cooling temperatures required for thermal comfort, the lighting required and the occupancy density for each zone, some of which are described in Table 5 and section 3.5. The remaining is described below.

3.6.1. Occupancy Schedule

Considering the yearly curricula of Iranian schools, especially in tropical areas, the daily occupancy of the building and the yearly HVAC schedules cannot be calculated according to standards such as ASHRAE. Schools in the rural tropical regions of Iran are usually open from Saturday to Wednesday from 7 A.M. to 5 P.M. Moreover, they are closed from June 1 to Sep. 20 (summer holidays) as well as from March 18 to April 5 (Nowruz holiday during these periods, the HVAC systems are turned off and minimum lighting is required in the buildings[7]. In other months, the school buildings are closed after 5 P.M. and on Thursdays and Fridays. Hence, minimum lighting and thermal requirements are calculated depending on the heating/cooling setback temperature. Given that Design Builder software and the Energy Plus engine are developed for the Gregorian months, the solar months are not necessarily used in this article, but the times are generally converted.

3.6.2. Thermal Comfort and Ventilation System

Considering the area of the building and problems such as the difficult transportation of fossil fuels to rural areas, the need to reduce the risk of fire in schools, and also the reduction of carbon dioxide emissions, a split system without mechanical ventilation was considered for cooling and heating this type of building. The heating seasonal CoP (Coefficient of Performance) of the system is 2.35 and its cooling seasonal CoP is 1.83. It should be noted that the present study aimed to find the optimal building orientation by comparing various model, so, the efficiency of the heating and cooling system played no role in the final result. In the modeled building, to provide thermal comfort, the heating and cooling temperatures for thermal were considered to be 21 and 24 °Celsius, respectively and the heating setback temperature[8] was considered to be 12 °C.

3.6.3. Schedule of HVAC Systems

In the design of building, thermal comfort is the condition of mind that expresses satisfaction with various factors such as temperature, humidity, and proper air flow rate. Most researchers believe that "thermal neutrality" is a more accurate definition of thermal comfort. Thermal neutrality refers to a condition where the human body does not feel the cold, nor the heat, nor the local discomfort caused by asymmetrical radiation, draft, cold room floor, heterogeneous clothes and so on. (Watson & Labs, 2010, p. 29). Researchers of the University of Kansas have found that people wearing plain office clothes are most satisfied in an environment with a dry temperature of 79 F and relative humidity of 50 percent and an air flow rate of less than 35 feet per minute (ASHRAE, 1981).

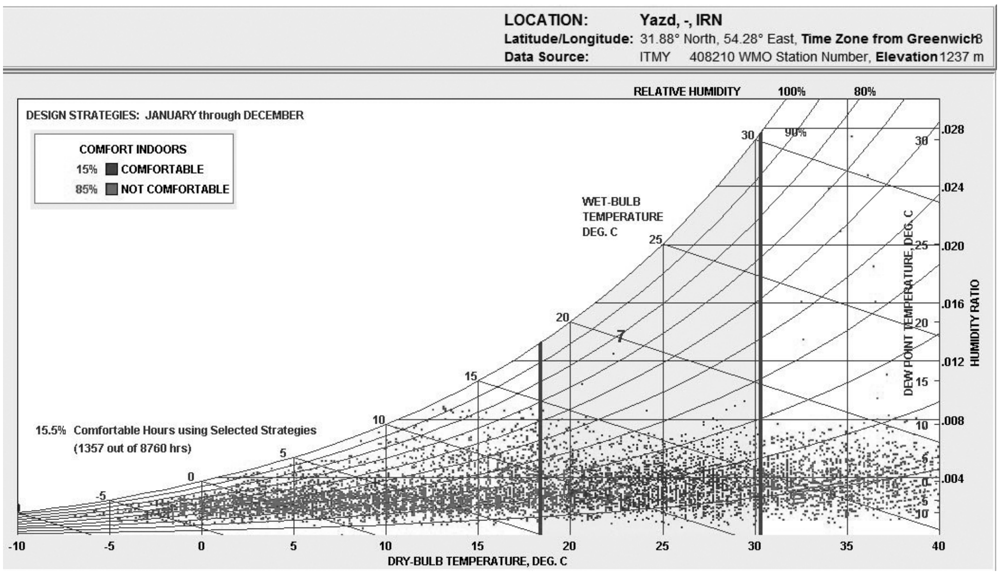


Fig. 4. Psychometric Curve of Yazd City According to the Standard
(Output of Climate Consultant Software, ASHRAE 55-2010)

Figure 4 shows the psychometric curve of Yazd City for a period from Jan. 1 to Dec. 31, according to the ASHRAE 55-2010, from January 1 to December. The horizontal axis shows the dry bulb temperature and the vertical axis shows the relative humidity (%). The red dots represent the hours when there is no thermal comfort and green dots shows the hours when there is thermal comfort. As seen in this figure, it is found that the total hours of thermal comfort during the year for Yazd City is 15.5% of the total hours of the year, i.e. 1357 hours out of 8760 hours. Similarly, for the cities of Isfahan, Zahedan, Shiraz, Qom, and Kerman, the same value was estimated to be 16.1, 16, 14.6, 17.3 and 14.9%, respectively. To make the study shorter, the psychometric curves of the other five cities are not presented here.

In general, thermal comfort depends on many factors such as air temperature, humidity, air flow, type of clothing, average radiant temperature, and so on. Since there is no approved standard for the Iranian cities, in the present study, the annual schedule of HVAC systems was determined according to the available weather data.

So, the weather data collected from 2013 to 2017 for each of the six cities were used to determine the annual schedule of HVAC systems as follows. Here, as an example, the weather data analyzed for Yazd city are presented:

To decide on the schedule of HVAC systems for Yazd City, the minimum and maximum monthly temperatures obtained from 2013 to 2017 were listed in a table and the 5 values reported for each month were averaged. Here, the tables are omitted and based on their results, Figure 5 was plotted. Analyzing this figure indicates that for Yazd City, only in April, May, and October, there is a need for a cooling system and there is no need for a heating system in May. During the summer holidays (June 1 to Sep. 20) and Nowruz (Mar. 18 to Apr. 5), the heating and cooling systems are turned off.

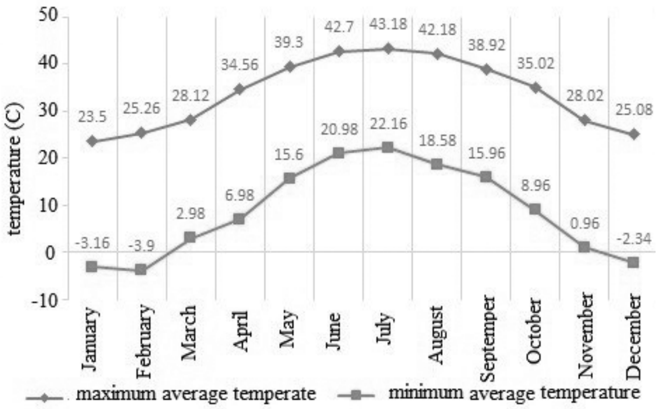


Fig. 5. The Maximum and Minimum Average Temperature of Yazd from 2013 to 2017 (The Specified Zone is the Thermal Comfort Limits)

Similarly, the abovementioned values were determined for the other five cities. Table 7 shows the average maximum and minimum temperatures from 2013 to 2017 for the six cities studied and the on/off status of the heating and cooling systems in different months of the year.

Table 7. Maximum and Minimum Monthly Average Temperature of the Six Cities in the Last Five Years and the On/Off Status of HVAC Systems in Each Month

		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Maximum Monthly Average Temperature (in the Last Five Years)	Isfahan	18.48	20.64	23.84	29.84	34.76	39.6	40.84	39.28	35.84	31.68	22.84	21.04
	Shiraz	20.6	21.4	24.6	31.52	36.6	40	41.16	40.08	37.08	32.56	25.56	21.88
	Zahedan	24.10	24.58	28.24	35.08	39.34	41.78	41.3	38.94	36.92	34.96	27.4	26.08
	Qom	19.64	23.02	27.2	34.86	38.98	43.78	45.56	43.66	40.88	36.36	25.86	19.86
	Kerman	22.14	23.14	25.62	31.94	36.36	39.52	39.66	38.28	35.76	32.82	27	24.66
	Yazd	23.5	25.26	28.12	34.56	39.3	42.7	43.18	42.18	38.92	35.02	28.02	25.08
Minimum Monthly Average Temperature (in the Last Five Years)	Isfahan	-8.12	-5.84	-0.32	3.84	10.12	16.44	18.92	15.72	11.56	5.32	-3.04	-5.72
	Shiraz	-4.52	-3.88	-0.56	4.16	9.28	13.48	17.32	15.36	11.36	6.44	0.2	-4.04
	Zahedan	-7.7	4.14	0.22	6.04	12.84	15	16.52	13.7	10.50	5.2	-1.88	-8.46
	Qom	-5.6	-4.92	-0.02	3.52	12.2	16.16	19.86	16.52	11.84	4.74	-3.06	-5.18
	Kerman	-11.58	-7.16	-2.56	3.22	8.08	11.74	12.62	9.24	8.22	2.68	-5.1	-10.06
	Yazd	-3.16	-3.9	2.98	6.86	15.6	20.98	22.16	18.58	15.96	8.96	0.96	-2.34
Heating	Isfahan	+	+	+	+	+	-	-	-	-	+	+	+
	Shiraz	+	+	+	+	+	-	-	-	-	+	+	+
	Zahedan	+	+	+	+	-	-	-	-	-	+	+	+
	Qom	+	+	+	+	-	-	-	-	-	+	+	+
	Kerman	+	+	+	+	+	-	-	-	-	+	+	+
	Yazd	+	+	+	+	-	-	-	-	-	+	+	+

		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Cooling	Isfahan	-	-	-	+	+	-	-	-	-	+	-	-
	Shiraz	-	-	-	+	+	-	-	-	-	+	-	-
	Zahedan	-	-	-	+	+	-	-	-	-	+	-	-
	Qom	-	-	-	+	+	-	-	-	-	+	-	-
	Kerman	-	-	-	+	+	-	-	-	-	+	-	-
	Yazd	-	-	-	+	+	-	-	-	-	+	-	-

4. METHOD

In the present study, considering the validity of Design Builder software, which has already been proven by researchers, it was decided to not perform field measurements. Then, to achieve the optimal building orientation in the mentioned cities, using the above-mentioned features, a computer simulation was performed. Next, for each of these cities, the orientation of the computer model was clockwise (geographically) rotated at five-degree intervals, and for each model, building energy simulations were performed and the results were recorded[9]. Building energy has been simulated 72 times for each city (a total of 432 times for the six cities studied).

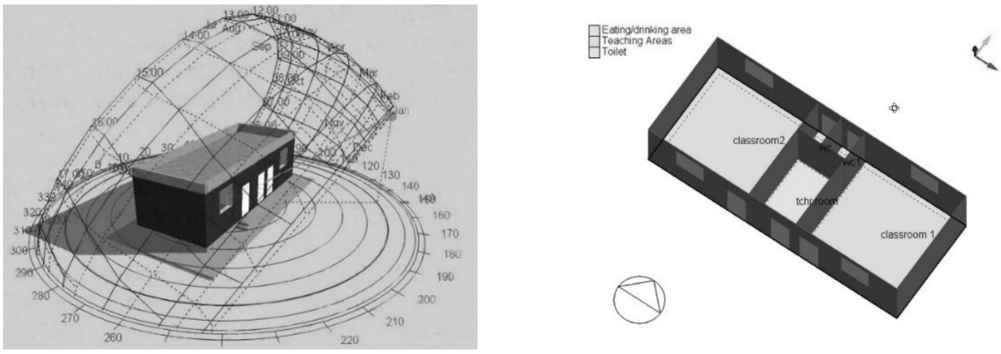


Fig. 6. Simulated Building on December 15 (Default Time) at 10 A.M.

The total annual energy consumption (kilowatt/hour) of 432 simulated models in the cities of Isfahan, Shiraz, Zahedan, Qom, Kerman, and Yazd are listed in a table not presented here[10]. These values are presented in Figure 9 for Yazd City, for example. Among the obtained values, the minimum values were found and a 10-degree range was identified as the minimum energy consumption range for each city. Then, to more accurately find the optimal building orientation in these ranges for the cities, various models were simulated in different directions with a one-degree variance and compared in the annual energy consumption.

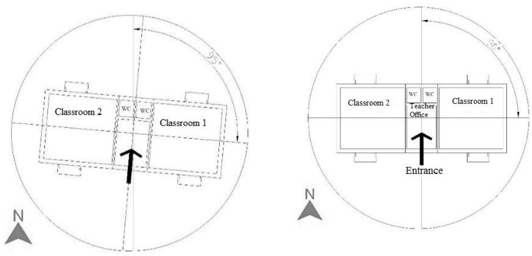


Fig. 7. The 5-Degree Rotation of Each Model Relative to the Previous Model (Models Nos. 19 and 20, Figure 9)

5. ANALYSIS

As mentioned, Figure 9 shows the obtained total annual energy consumption of 72 simulated models in different directions with a 5-degree variance for six different cities. It should be noted that the total annual energy consumption is the sum of the annual energy demand for indoor lighting, room electricity, annual cooling and heating, and domestic hot water consumption, as shown, for example, for the orientation of 90 degrees in Yazd City in Figure 8.

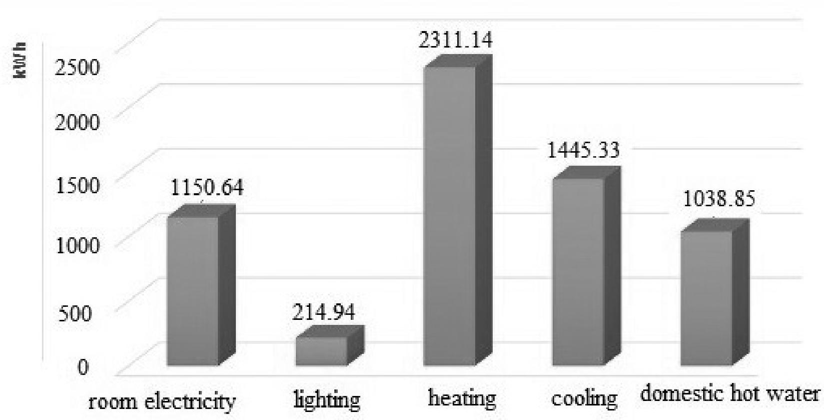


Fig. 8. Details of the Annual Energy Consumption of the Building with the Orientation of 90°, Yazd City

Here, for example, it is explained how the data are analyzed for Yazd City. The same was followed for other cities.

Examining the total annual energy consumption for Yazd city suggests that out of 72 simulated models, the eight models Nos. 15 to 22, which are related to the orientations of 70 to 105 degrees, have the minimum annual energy consumption. It is clear from Figure 9 shows a decreasing trend in the two ranges and the above mentioned range (from 70 to 105 degrees). Figure 10 shows the annual energy consumption of the models Nos.15 to 22.

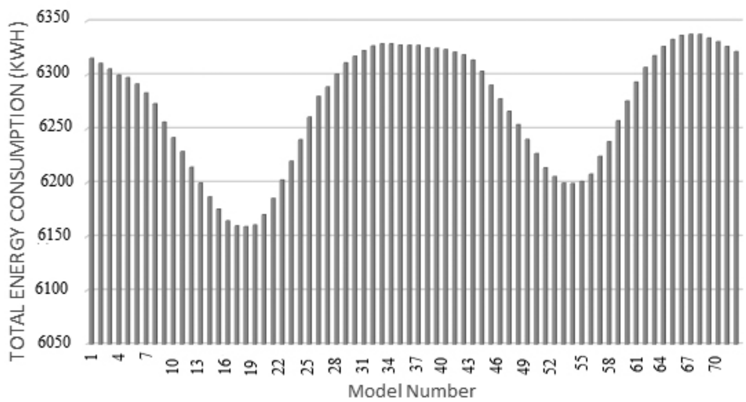


Fig. 9. Total Annual Energy Consumption of 72 Simulated Models with Different Orientations, Yazd City

Analyzing the latest figure shows that for Yazd City, with the orientation ranging 80-90 degrees, the annual energy consumption is less than 6190 kWh. So, the final model with the minimum annual energy consumption is found in this range. To achieve this model, the abovementioned ten-degree range was investigated with eleven models as follows: the longitudinal axis of each model is rotated one degree clockwise (geographical direction) relative to its previous model. The results of these 11 final models are found in Figure 11.

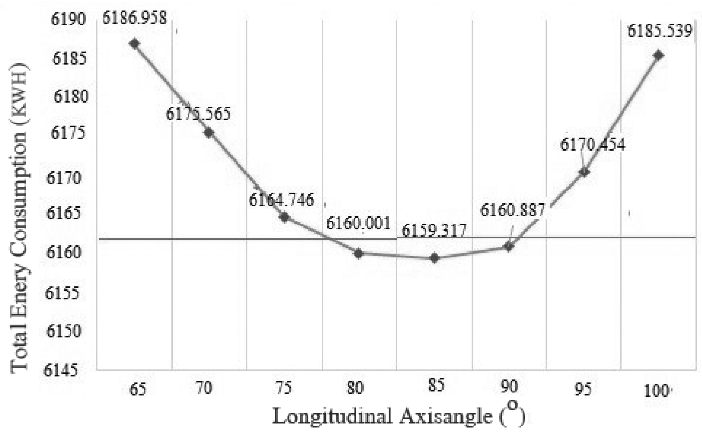


Fig. 10. Total Annual Energy Consumption of the Eight Models with the Minimum Energy Consumption in Yazd City (The Area under the Blue Line Has the Minimum Annual Energy Consumption)

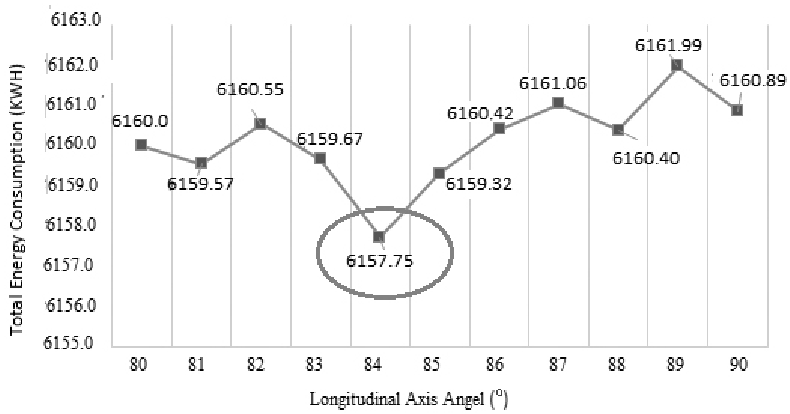


Fig. 11. Total Annual Energy Consumption of Final Models with 1-Degree Difference in Orientations, Yazd City

As this figure shows, for Yazd City, with the orientation ranging 80-90 degrees, the total annual energy consumption of the building is periodic and its minimum value (6157.75 kWh) is obtained at an angle of 84 degrees. Similarly, for the cities of Isfahan, Zahedan, Shiraz, Qom, and Kerman, the values of 6593.653, 5109.634, 5630.829, 6446.135, 5527.306 kWh were obtained as the minimum annual energy consumption, which are related to the orientations of 84, 98, 76, 80, and 84 degrees, respectively. In the current conditions of construction, using survey cameras allows implementing the building orientation with a 1-degree precision, but no higher precision is possible. Therefore, modeling was not continued.

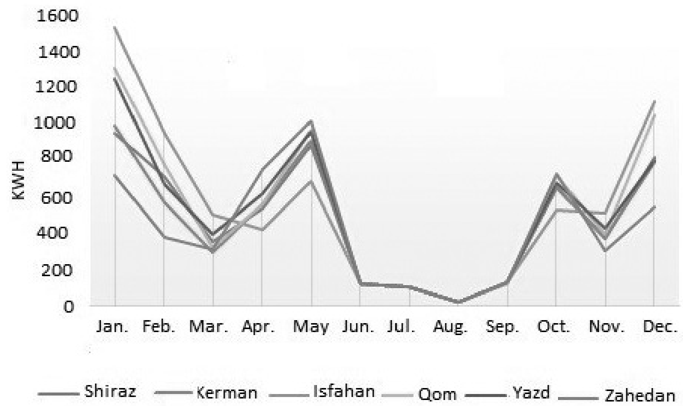


Fig. 12. Monthly Energy Consumption in the Final Optimal Models

Figure 12 shows the monthly energy consumption of the final models obtained for the six cities studied. As seen, in all six models, the maximum energy consumption was calculated for January and the minimum value for March and November (the building is not used from June to September, and also 12 days in March (these are school holidays).

In Yazd City, using the 335-degree building orientation (considering "0" in the north) results in the highest annual energy consumption of 6337.783 kWh and the difference between this value and the minimum energy consumption is 180.033 kWh.

The useful life span of school buildings in Iran is 50 years[11] (Interview with the head of the Iranian Organization for Development, Renovation and Equipping of Schools, August 26, 2009). The value of energy saving (E_t) in all double-class school buildings in the country (or a province) during the useful life span of these buildings can be calculated using the following formula:

$E_t = n \times 50 \times E1$

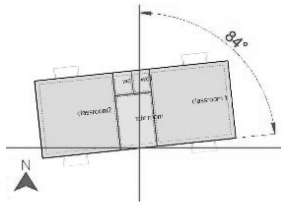
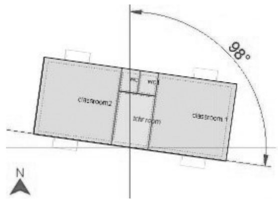
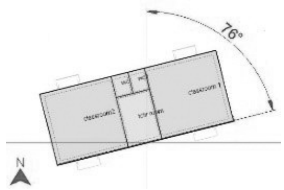
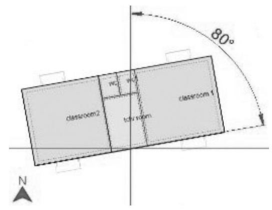
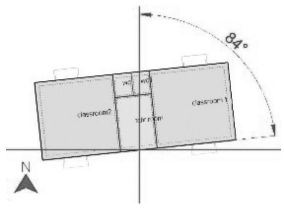
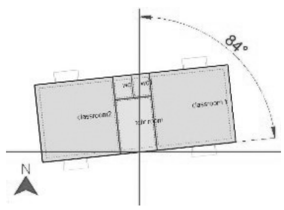
Where, n is the number of schools built with this plan across the country (or province) and E1 is the annual energy saving of a school. If the large number of schools built in the country over a five-year period is taken as an example, it will be easy to understand how much energy efficiency will be enhanced only by modifying the building orientation, highlighting how important the results of the present study are.

Except for Kerman City, for which the prevalent orientation was found, for other cities, the impact of optimal orientation energy efficiency (in%) can be calculated using the following formula:

$$(\%)\ \text{Impact of Optimal Orientation on Annual Energy Efficiency} = 100 \times \frac{\left(\text{Maxmimum Annual Energy Consumption}\right) - \left(\text{Minimum Annual Energy Consumption}\right)}{\left(\text{Minimum Annual Energy Consumption}\right)}$$

For Kerman City (where there is a prevalent orientation for school buildings), the formula given in section (1.3) was used. Using the formulas abovementioned, the values obtained for the cities of Isfahan, Zahedan, Shiraz, Qom, Kerman, and Yazd were 3.12, 3.31, 3.27, 6.16, 4.38, 2.92%, respectively. Table 8 shows the minimum and maximum annual energy consumption, the impact of the optimal orientation on energy efficiency and the images of the optimal model for each city. Figure 13 compares the final percentages.

Table 8. Minimum, and Maximum Annual Energy Consumption and the Optimal Models for the Six Cities Studied

City	Longitude Axis Angle of the Optimal Model (°)	Minimum Annual Energy Consumption (kWh) of the Optimal Model	Maximum Annual Energy Consumption (kWh) of the Most Inappropriate Model	Impact of Optimal Orientation on Energy Efficiency (%)	Optimal Model
Isfahan	84	6593.653	6799.51	%3.12	
Zahedan	98	5109.634	5279.047	%3.31	
Shiraz	76	5630.829	5815.467	%3.27	
Qom	80	6446.135	6843.55	%6.16	
Kerman	84	5527.306	5769.405	%4.38	
Yazd	84	6157.75	6337.783	%2.92	

Finally, despite the small impact of building orientation on the annual energy consumption, determining the optimal orientation becomes clearly important when a large number of typical buildings are built and their useful life span of 50 years is considered. As a result, it is found that paying attention to the proper building orientation can save a lot of energy in the long run.

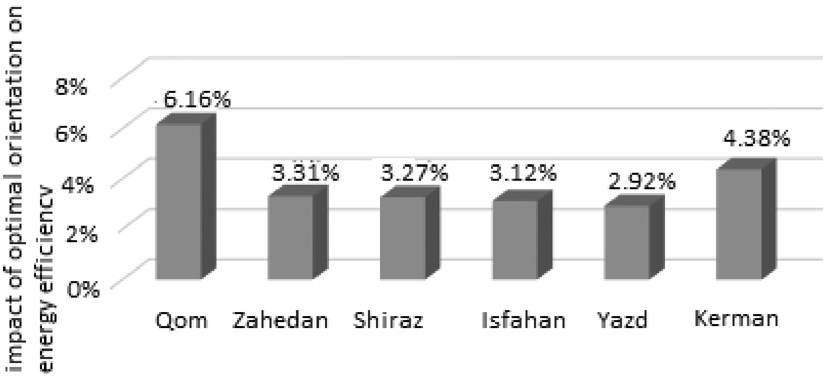


Fig. 13. Comparison of the Six Cities in Terms of the Impact of the Optimal Building Orientation of Schools on Energy Efficiency

6. RESULTS AND SUGGESTIONS

After analyzing the data and reviewing the plotted charts, the research questions were answered and specific results were considered a summary of them are as follows:

- The lowest values of the annual energy consumption for the double-class schools in the cities of Isfahan, Zahedan, Shiraz, Qom, Kerman, and Yazd were estimated 6593.653, 5109.634, 5630.829, 6446.135, 5527.306, 6157.75 kWh, respectively. These values were obtained for the longitudinal axis of 84, 98, 76, 80, 84, and 84 degrees (taking 0 in the north and clockwise rotation).
- Calculations revealed in these cities, in the case of the double-class school, constructing buildings with their optimal orientations would result in 3.12, 3.31, 3.27, 6.16, 4.38, 2.92% rise in energy efficiency, respectively.
- In Kerman City, the northeast-southwest orientation can be considered as the prevalent orientation of most school buildings under construction, but in other cities, no prevalent orientation was found. In rural areas, since there are no limitations on the orientation of urban streets, the optimal building orientation can be carefully determined during the execution of the plan.
- Considering the large number of typical buildings built with this plan and their life span of 50 years, saving a small amount of energy in a building during the year will be result in significant energy savings at the national level, highlighting the importance of determining the optimal building orientation during construction.
- There are no sunshades in the current drawings. However, if the sunshades are considered for the models, the values will be slightly different. Therefore, parametric modeling using Galapagos plugin in Rhinoceros software, to find the optimum shading length and the optimal orientation in accordance with it, can be the topic of future research.
- There are many factors influencing energy efficiency which can be investigated in future research. For example, one can mention the factors of optimization of materials and the use of thermal wall insulation in walls, thermal ceiling insulation, structural layers used in the roof, window-to-wall ration, sill height, window orientation, the optimum shading length and shading form, the classroom depth, and the arrangement and location of classrooms in the plan if there are more classrooms.

END NOTE

1. https://energyplus.net/weather-region/asia_wmo_region_2/IRN%20%20, Received Date:10/Feb/2019
2. Interview with the head of the Iranian Organization for Development, Renovation and Equipping of Schools
3. ASHRAE:(The American Society of Heating, Refrigerating and Air-Conditioning Engineers)
4. The lux is the SI derived unit of illuminance, measuring luminous flux per unit area. It is equal to one lumen per square metre.
5. The fraction of heat from lights that goes into the zone as long-wave (thermal) radiation.
6. The fraction of heat from lights that goes into the zone as short-wave (thermal) radiation.
7. According to the settings of the simulation software, the Gregorian months were used.
8. It is the minimum temperature that is maintained by heating systems, during the hours when the building is not used temporarily, to reheat the building with less energy or quickly.
9. In the whole text, the values reported for orientations are based on the geographical degree (clockwise rotation) with zero in the north.
10. To receive this table, you can contact the corresponding author.
11. https://www.mehrnews.com/news/915973

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Appendix:

Table 9. Properties of External Glazing

Double- Clear- 6mm/13mm Air	
Total Solar Transmission(SHGC)	0.497
Direct Solar Transmission	0.373
Light Transmission	0.505
U-value(ISO 10292/EN 673) (W/m^2-k)	2.785
U-value (ISO 15099/NFRC) (W/m^2-k)	2.665

Table 10. Properties of Lights

LED with Linear Control	
Normalized Power Density(W/m^2-100 lux)	2.50
Luminaire Type	Recessed
Radiant Fraction	0.37
Visible Fraction	0.18

Table 11. Properties of Walls, Ceiling and Window Frames Used in the Models

	External Window Frames	External Wall	Roof
Inner Surface			
(Convective Heat Transfer Coefficient (W/m^2-k	2.152	2.152	3.805
Radiative Heat Transfer Coefficient (W/m^2-k)	5.540	5.540	5.540
Surface Resistance (m^2-K/W)	0.130	0.130	0.107
Outer Surface			
Convective Heat Transfer Coefficient (W/m^2-k)	23.290	19.870	28.203
Radiative Heat transfer Coefficient (W/m^2-k)	1.710	5.130	5.130
Surface Resistance (m^2-K/W)	0.040	0.040	0.030
With No Thermal Bridge			
U-Value Surface to Surface (W/m^2-k)	23.853	2.442	0.618
R-Value (m^2-K/W)	0.212	0.580	1.754
U-Value (W/m^2-k)	4.719	1.725	0.570
With Thermal Bridge (Per ISO 6946)			
Thickness(m)	0.009	0.2850	0.0682
Km-internal Heat Capacity (KJ/m^2-K)	3.9675	149.0240	195.088
Upper Resistance Limit (m^2-K/W)	0.0212	0.580	3.323
Lower Resistance Limit (m^2-K/W)	0.212	0.580	3.323
U-Value Surface to Surface (W/m^2-k)	23.853	2.442	0.314
R-Value (m^2-K/W)	0.212	0.580	3.323
U-Value (W/m^2-k)	4.719	1.725	0.301