# Finding the Best Orientation of the Educational Buildings in Hot Arid Regions in Iran, in order to achieve theOptimum Annual Energy Consumption, Using Computer Simulation (Case Study: a Double Class School in *Zahedan*)

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**Abstract**

School buildings forming a large part of the public buildings, are among the most important consumers of energy in Iran. Given the existing construction conditions, these buildings seem to have considerable potential for energy efficiency if the construction and design methods are reformed. Therefore, numerous researchers have analyzed geometrical factors influencing energy consumption in buildings, but few researchers have specifically and precisely studied building orientation. In this research, a two-classroom school with a simple and extendable plan, typical of hot and arid regions in Iran was studied. The objective is to conclude optimum orientation for minimum energy demand, taking into consideration the provision of a thermally comfortable environment inside. Building performance simulation (using Design Builder[i] software) was applied to support design optimization. To this end, 72 models were simulated in different directions with a 5-degree variance, and the 10-degree range of the minimum annual energy consumption was obtained. Afterward, the simulation with the 1-degree variance was repeated using the same range and the results were compared. Finally, it was suggested that the model with the orientation of 109[ii] degrees longitudinal yields the minimum energy consumption. Other methods of saving energy in this region were also discussed. Consequently, the comparison of the results revealed that the effect of building orientation on reducing annual energy consumption in *Zahedan* is noticeable, considering the number of typical buildings and life span of the buildings.

***Keywords:*** Orientation; Energy Efficiency; Computer Simulation; Schools; *Zahedan*; Iran

## 1. Introduction

The energy crisis has evolved into a global challenge that increasingly becomes more serious. In addition, cutting edge technologies and energy efficiency measures have been developed significantly and it is necessary to identify those technologies and measures that will be more effective and reliable in the long term.

Accordingly, various energy efficiency methods and measures have been suggested, so as to enable decision makers in construction projects to analyze different environmental, economic, and social factors more effectively and to choose the best solution that not only maximizes building energy efficiency, but also meets users', residents', and owners' needs (Diakaki et al., 2008: 1).

Buildings, their settings, and related construction enterprises produce the largest amount of carbon dioxide and consume energy and natural resources more than any other human enterprise or industry (Sozer, 2010: 1). Research findings also suggest that almost 40% of the total energy production in the developed countries is consumed in the building sector, especially by HVAC systems (Carroll, 1982; Kolokotsa et al., 2011). Moreover, one-third of the greenhouse gas emissions originate from buildings (Robert & Kummert, 2012).

In Iran, the energy used in buildings accounts for about 40.6% of the total energy consumption throughout the country (Ministry of Energy, 2013) that costs 6 billion dollars a year (Development and Promotion of National Building Regulations Office, Introduction, 2009).

The average energy consumption in Iranian school buildings as the most common public buildings is 160kWh/m$^2$ (Iranian Fuel Conservation Organization, 2009), which is 2.5 times greater than the annual energy consumption in the developed countries, which is approximately 65kWh/m$^2$ (Im & Haberl, 2006). Despite the high energy consumption in Iran, thermal comfort is still lacked in many classrooms. There is also no code or standard for the construction of schools to reduce energy consumption levels.

Climate Zone of *Zahedan* City According to Organization for Development, Renovation and Equipping Schools of Iran, is located in a hot and arid region (Kasmaee, 1994), and although the schools locating in hot and arid regions account for 41.9% of the total energy consumed in Iranian schools, no design instruction or code has been formulated (Joshghani, 2001).

Generally, buildings are constructed for the purpose of being occupied for at least 60 to 80 years or sometimes

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even more than 100 years. Hence, valuing energy efficiency of buildings in their design phase is of paramount importance, because doing so would be more difficult following the primary construction phase (Laustsen, 2008:7). This highlights the importance of building simulation for the attainment of different goals including energy efficiency.

Engineers and researchers have been using computers to simulate the building construction processes for more than four decades (Oberkampf & Trucano, 2002). Concerns over the organization of the world’s energy reserves and environmental protection have aroused a global concern about the large volume of energy consumed yearly in buildings considering its environmental impacts. Building Energy Simulation (BES) Software plays a major role in reducing energy consumption in built environments. Through energy simulation, the different aspects of a building are analyzed prior to its construction, and actions are taken to reduce its energy consumption. Moreover, computer modeling and simulation constitute one of the techniques that have been proven to be reliable and valid in the assessment of building energy consumption patterns. Today, numerous simulation software solutions (e.g., eBlast, Doe2, EFEN, Energy Express, Energy Plus, TRNSYS, and Quest) are available for the assessment of the total energy consumption of the buildings.

In addition, architectural design drastically influences the consumption of nonrenewable resources in buildings. Some of the architectural and geometrical determinants of the energy consumption in buildings are the window to wall ratio, sunshades, and building orientation.

The proper use of geometrical parameters of buildings, rooms, openings, and other opening-related elements such as sunshades and windows significantly reduce energy consumption in buildings and improves their energy-saving performance (Susorova et al., 2013).

Also, researchers have found that the daily and seasonal moving and transposition in different directions of the houses, subdivision, and unification of spaces, which we can name it "flexibility" affects the energy efficiency of the traditional Iranian houses, especially in Kashan. (Hashemi Rafsanjani & Mahdavinejad, 2015)

Building orientation as an important architectural factor is closely linked to the annual energy consumption in buildings. When a building is constructed with optimum orientation, sunlight is used more effectively, daylight reaching the interior spaces increases during winters, and fuel consumed for the provision of cooling, heating, and lighting decreases. Some researchers have addressed the building geometrical factors but few have specifically focused on building orientation.

In the past, building orientation was selected based on the view, the prevailing wind, site topography, adjacent buildings, etc. Sometimes the building orientation was determined based on the actual urban design factors such as the historical texture or other factors. Selecting a suitable orientation for a building based on the prevailing wind direction for improving cross-ventilation in that building or constructing the building in a certain direction for maximizing absorption of heat from the sunlight during winter is not often possible due to the aforementioned reasons.

Selecting a suitable building orientation affects natural ventilation, absorption of daylight, absorption of heat from the sunlight during cold months, and reduces absorption of heat from sunlight during hot months. Hence, finding the best building orientation is supposed to reduce the annual building energy consumption. Therefore, computer simulation was used in this study to prove this hypothesis.

The focus of the present study was on two-classroom schools located in and around *Zahedan* (29.4519° N, 60.8842° E, 1370 m), which represents cities in arid and hot parts in Iran.

The objective is to propose a method to calculate the best orientation of school buildings in hot and dry climate of Iran with regard to optimization of energy consumption and occupant`s interior thermal comfort.

The methodology of doing this research is through modeling the mentioned school building in different directions using computer simulation with the Design Builder software and comparing the calculated energy consumptions.

This study attempts to answer the following questions:

Is there a common orientation for the schools that are being built in *Zahedan*?

What is the rate of which the building orientation reduces the annual energy consumption in this region?

What building orientation best serves energy efficiency in *Zahedan*?

## 2. Reviewing Previous Literature

The literature shows that few studies have been carried out on school buildings, instead focusing on residential and office buildings to assess energy efficiency, building form, building materials, construction types, and HVAC[iii] systems rather than the effect of building geometrical factors on energy consumption patterns.

Steadman (2014) proposed five school plans for England and compared them in terms of plan compaction, south wall ratio, the percentage of circulation area, daylight, and traffic distances. His findings indicated that open-air schools benefit from better ventilation, daylight, and exposure to nature depending on the weather conditions. (Steadman, 2014)

Montenegro et al. (2012) introduced nine different school types for the cold climate of Montreal (Canada) and the mild and humid climate of Santiago (Chile) and compared them in terms of visual, thermal, and energy performance. They concluded that schools with linear topologies showed the best performance in both climates (Montenegro et al., 2012).

Da Graca et al. (2007) classified school building plans in Sao Paulo (Brazil) and proposed a method of assessing and optimizing different parameters of school buildings based on four aspects of comfort including thermal comfort, acoustic comfort, natural lighting, and functional comfort. Their findings revealed that the concurrent optimization of all of the mentioned aspects of comfort is not possible, although there is agreement on some aspects (Da Graca et al, 2007).

Dimoudi and Kostarela (2009) briefly introduced different school building plans for C' climate zone in Greek, which had the lowest temperature during winter. They analyzed the thermal performance of a school type known as the "Athina" type and proposed various energy saving solutions (Dimoudi & Kostarela, 2009).

Su (2013) studied the relationship of the main building design factors including the building envelope with extra energy consumption during winter (which is associated with heating and hot water) and other performance factors involved in the interior comfort during winter. Several schools selected randomly in Auckland (New Zealand). Their findings revealed that the designs commonly used in the schools of Auckland, where the ratio of the building exterior surface to its volume was high, did not suit the climatic conditions of the region. Hence, an attempt was made to reduce the number of isolated schools to lower energy consumption and increase the height and volume of schools by building more concentrated and compact buildings (Su, 2013).

Zhang et al. (2017) adopted a genetic algorithm to optimize thermal and daylight efficiency in school buildings in the cold areas in China and simulated and compared three different plans with different sunshades, windows, and room and corridor depths. It was found out that the schools with the two-way corridor had the best thermal and daylight performance in that climate zone. Other parameters were also introduced (Zhang et al., 2017).

Ouf and Issa (2017) assessed the energy consumption levels in 30 old school buildings within a 10-year period in the cold climate of Manitoba (Canada). Their goal was to develop an energy consumption benchmark for Manitoba schools that could be used in similar cold climates too. They concluded that the total average energy consumption of the buildings was higher than other Canadian benchmarks. Besides, the lifetime of school buildings was found to have a statistically significant impact on their energy consumption. The natural gas use decreased but electricity consumption increased following the building renovation, which was possibly caused by the larger number of students in the new schools. Alterations to some old school buildings influenced their energy consumption, but it was not generally observed in all schools. Moreover, the buildings with an average lifetime had the highest energy consumption level (Ouf & Issa, 2017).

Lou et al. (2017) assessed energy saving and electricity production in a school building in a hot and humid climate using eQUEST Building Energy Package. They used the optimum building envelope and lighting and ventilation systems with optimum energy efficiency in the building. They also provided the building with integrated photovoltaic (BIPV) panels. It was found out that 97.5% of the annual electricity demand of the building can be supplied by using photovoltaic panels installed perpendicular to the building façade wall. It was also found that more electricity can be generated by placing these panels on the roofs and enhancing the zero building energy consumption condition (Lou et al., 2017).

In another study, Wang (2016) measured energy consumption in 51 universities, 7 high schools, 11 secondary schools, and 5 elementary schools. He reported that energy consumption at universities was extremely higher than that of all the schools due to the complicated functions and the use of training, research, and laboratory equipment of the universities. The universities where academic research was conducted consumed more energy than the universities that delivered only education services. Moreover, the energy consumption in school buildings and the relationship between energy consumption variables were assessed through regression analysis. Ventilation and lighting were found as two key factors influencing the energy consumption in school buildings. Several energy efficiency techniques were also proposed at the end of the article (Wang, 2016).

Tahsildoost and Zomorodian (2015) explored the optimization and modification of energy consumption of two typical schools in Iran from the pre- and post-2000s periods through a step-by-step process. First, a preliminary assessment of the buildings was carried out to find the solutions in the next stage. Afterward, building energy modeling and a payback time (PBT) analyses were carried out. In the third step, the implemented techniques were assessed. The energy modeling revealed that sealing the windows, replacing the old windows, and insulating the roofs were among the most effective solutions. The adoption of these solutions resulted in about 30% and 38% of energy saving in the old and new schools, respectively. Moreover, the results from the questionnaires completed by the students showed an improvement in the quality of interior spaces (Tahsildoost & Zomorodian, 2015).

In the case of *Zahedan*, no researcher has yet scrutinized the school's climatic design criteria. But some researchers have studied hot and dry schools around the world, briefly referred to here:

Zomorodian and Nasrollahi (2013) studied the architectural parameters (building form, spatial organization, and the window to wall ratio) of school buildings in hot and arid regions in Iran. They managed to modify the parameters in question through computer simulations and offer suggestions to improve energy efficiency. Their study shows that the energy demand in the studied schools was reduced by 31% after altering the architectural parameters without making any changes in the building materials and structural parameters (Zomorodian & Nasrollahi, 2013).

Canton et al. (2014) developed an empirical and theoretical model to assess yard shape as a passive strategy for improving thermal comfort in classrooms in Mendoza, Argentina. Their findings revealed that the shading pattern used in school yards was the most important determinant of the energy and thermal performance of classrooms (Canton et al., 2014).

In an effort to find a way to reduce energy consumption in the buildings of hot arid climate of Nigeria, K.M Odunfa et al, have investigated the orientation and energy consumption of houses built in different parts of Ibadan, the largest city in West Africa. As a result, it has been found that houses with an East-West orientation need to consume more energy for internal cooling than those with a North-South direction (K.M Odunfa et al., 2013). In this study, only two major orientations are considered.

K. ElAzhary et al (2019) aimed to evaluate the impact of building orientation and local architecture on energy consumption and better design of buildings in terms of energy efficiency, the thermal behavior of a traditional building in the hot and dry climate in Risana, Morocco has been evaluated, and it has been attempted to bring the building closer to the zero energy conditions. After the simulation, they have also suggested an optimal orientation for the building (K. ElAzhary et al., 2019). The accuracy of these researchers' calculations for simulated samples was 5 degrees.

Omaimah & Awadallah (2016) have investigated a school in hot and dry climate in Jordan by simulating with the Design Builder software in order to find optimal solutions to reduce the energy consumption needed to provide thermal comfort in the classrooms. They have changed the parameters and have achieved some results after 108 simulation and comparing the data. These researchers have compared only the two major N-S and E-W orientations (Omaimah & Awadallah, 2016).

As it can be seen as a brief analysis of the research gap, the orientation of school buildings was not the main focus of the aforementioned studies, and several studies generally assessed geometrical and architectural dimensions of buildings. However, the sporadic discussions presented in the literature are of limited accuracy ranging from 5 to 15 degrees. Given such a gap in the literature, the main objective of the present study was to provide a detailed analysis of the building orientation as a geometrical parameter.

## 3. General Considerations

Given the importance of energy efficiency, regions with inclement weather conditions are generally selected to study energy efficiency. These regions cover a large area on the earth. In particular, a large part of Iran, which is the focus of this study, is composed of arid and semi-arid regions. Researchers have analyzed various factors (climate, geomorphology, geology, pedology, hydrology, and vegetation) to identify deserts in Iran (Najafi Tireh Shabankareh et al., 2008). According to the survey results, the total surface area of lands that can be considered deserts based on at least one of the mentioned factors equals 985798 $km^2$, accounting for 59.8% of the total area of Iran with an arid and semiarid climate (Khosrowshahi & Kalirad, 2013: 27)

With a population of approximately 580,000 persons in 2016, *Zahedan* is an important city in the southeast of Iran. This city has an arid, dry and inclement climate characterized by difference sharp contrast in day and night temperatures, low annual precipitation, and low relative humidity.

The building under study is a two-class school. The school plan can be easily implemented in the distant desert villages with the minimum number of workers and minimum materials. In addition, since the urban texture limitations such as street orientations do not mainly impact the building orientations in their site, there is a space for them to be located on the property more freely.

Many schools have been built based on the typical plan in hot and arid regions. Currently, 439 schools have been constructed in the *Sistan Baluchestan* province[iv] . Since this plan is used to build a large number of schools, a very small reduction in the annual energy consumption in buildings (such as several kWh) may result in considerable energy savings due to a large number of these buildings in the deserts in Iran. Carbon dioxide emissions can be also reduced significantly.

Accordingly, the present study was an attempt to identify the optimum orientation to be used to reduce the annual energy consumption to a minimum level. To this end, computer simulations of the school building were carried out in specified directions, and accordingly the annual energy consumptions resulting from different models were compared.

### *3.1 The Prevalent orientation of schools in the region*

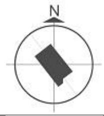
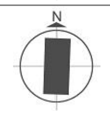
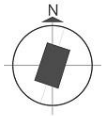
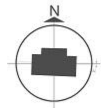
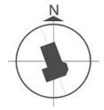
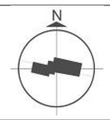
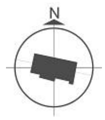
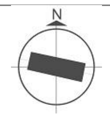
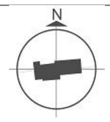
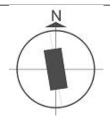
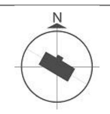
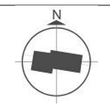
To find the probable common orientation in school buildings constructed in *Zahedan*, 21 schools used at different education levels were examined and the results are displayed in Table 1.

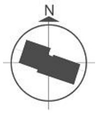
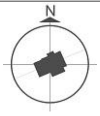
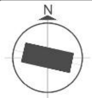
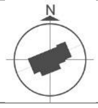
It was determined from the survey that building orientation has not been valued adequately for the construction of schools in the urban texture of *Zahedan* firstly due to their conformity with the existing urban context and the street orientations and secondly due to the lack of construction rules and regulations.

Figure 1 shows 4 examples of schools built in Zahedan, with different orientations. In the traditional Iranian architecture that can be often seen in Iranian cities, three general building orientations were commonly used depending on the climatic conditions. These orientations were known as “Ron”. The “Kermani orientation” is an east-west direction, which can be found in Kerman and Hamedan cities, and villages in West Azerbaijan. “Isfahani orientation” is a northwest-southeast direction used in Isfahan, Estakhr and Persepolis. The “Rasteh orientation” also is a northeast-southwest direction that is mostly found in Tabriz, Tehran, and Yazd (Pirnia, 2005). According to some researches in the city of Kashan, compliance with northeast to southwest “Ron” has been observed, especially in residential homes (Rezazadeh Ardebili, &Shafiei, 2016)

However, since Zahedan was established about 100 years ago, thus the city lacks any considerably historical architecture and buildings and do not have such a common orientation. Another reason is that due to the remoteness of the Sistan and Baluchestan region from the populated urban centers in Iran, professional master builders were less likely to come to the region.

Table 1
The results of the survey on orientation in 21 school buildings constructed in *Zahedan* (Source: Authors)

| | **Name of school** | **Grade** | **Latitude** | **Longitude** | **Orientation ($^0$)** | **Diagram** |
|---|---|---|---|---|---|---|
| **1** | Allame Helli | Elementary | $29^0$ 29′ 15″ N | $60^0$51′ 42″ E | 143-323 |  |
| **2** | Daneshgah for Boys | High school | $29^0$ 28′ 20″N | $60^0$ 51′ 41″ E | 110-290 |  |
| **3** | Daneshgah for Girls | High school | $29^0$ 28′ 26″ N | $60^0$ 51′ 34″E | 3-183 |  |
| **4** | Esteghlal | Elementary | $29^0$ 30′ 51″N | $60^0$ 52′ 51″ E | 18-198 |  |
| **5** | Farhangian for Boys | High School | $29^0$28′53″ N | $60^0$ 49′ 44″E | 93-273 |  |
| **6** | Farhang Girl`s | High School | $29^0$ 28′ 30″ N | $60^0$ 50′ 19″E | 160-340 |  |
| **7** | Farzanegan for Girls | High school | $29^0$ 28′ 27″ N | $60^0$ 50′ 30″ E | 21-201 |  |
| **8** | Fatemieh | High school | $29^0$ 30′ 03″ N | $60^0$ 51′ 59″ E | 102-282 |  |
| **9** | Haj Ibrahim Zamiri | High school | $29^0$ 29′ 42″ N | $60^0$ 50′ 02″ E | 102-282 |  |
| **10** | Imam Hassan Asgari | Elementary | $29^0$ 29′ 39″ N | $60^0$ 50′ 15″ E | 102-282 |  |
| **11** | Imam musa Kazem | High School | $29^0$ 29′ 22″ N | $60^0$ 50′ 12″ E | 86-266 |  |
| **12** | Imam Reza | ……….. | $29^0$ 30′ 17″ N | $60^0$ 49′ 59″ E | 100-280 |  |
| **13** | Motahareh | High school | $29^0$ 31′ 16″N | $60^0$ 51′ 09″ E | 171-351 |  |
| **14** | Sarani | Elementary | $29^0$ 30′ 05″N | $60^0$ 53′11″ E | 120-300 |  |
| **15** | Shahed 2 | High School | $29^0$ 29′ 48″ N | $60^0$ 50′ 22″ E | 99-279 |  |

| | | | | | | |
|---|---|---|---|---|---|---|
| **16** | Shahid Sabzkar | High School | $29^{0}$ 29′ 08″ N | $60^{0}$ 51′ 43″E | 94-274 |  |
| **17** | Shahid Sadooghi | Elementary | $29^{0}$ 30′ 23″ N | $60^{0}$ 51′ 20″ E | 108-288 |  |
| **18** | Somayyeh | Elementary | $29^{0}$ 28′ 30″ N | $60^{0}$ 50′ 13″ E | 67-247 |  |
| **19** | Velayat | High School | $29^{0}$ 27′ 29″ N | $60^{0}$ 52′ 27″ E | 69-249 |  |
| **20** | 14th khordad | Middle school | $29^{0}$ 30′ 03″ N | $60^{0}$ 51′ 04″ E | 103-283 |  |
| **21** | 29th Farvardin | Elementary | $29^{0}$ 28′ 05″ N | $60^{0}$ 52′ 22″E | 67-247 |  |

### *3.2 Simulation Software*

In the present study, Energy Plus calculation engine was used to calculate the annual energy consumption of the simulated models. Used by engineers, architects, and researchers, Energy Plus is a thermal simulation program that allows for the analysis of energy and thermal load on buildings. This software simulates the heating, cooling, lighting, ventilation, and water consumption models for buildings (Crawley et al, 2008; Crawley et al, 2001).
Energy Plus is an engine for the simulation and calculation of energy, which has been developed and sponsored since 1996 by the United States Department of Energy (DOE) (Crawley et al, 2008).

To design a building in accordance with climate, Design-Builder is used, which is not only capable of displaying and designing buildings but also uses the EnergyPlus calculation engine.
Design Builder utilizes a user-friendly interface, a meteorological database, and a sophisticated model to assess internal and solar energies (Tronchin & Fabbri, 2008: 1178). This software calculates a wide range of environmental performance data such as the energy consumed for heating and cooling, securing thermal comfort, and providing hot water, and the total annual energy consumption. These results are obtained within sub-hourly simulation time periods in the Energy Plus simulator.

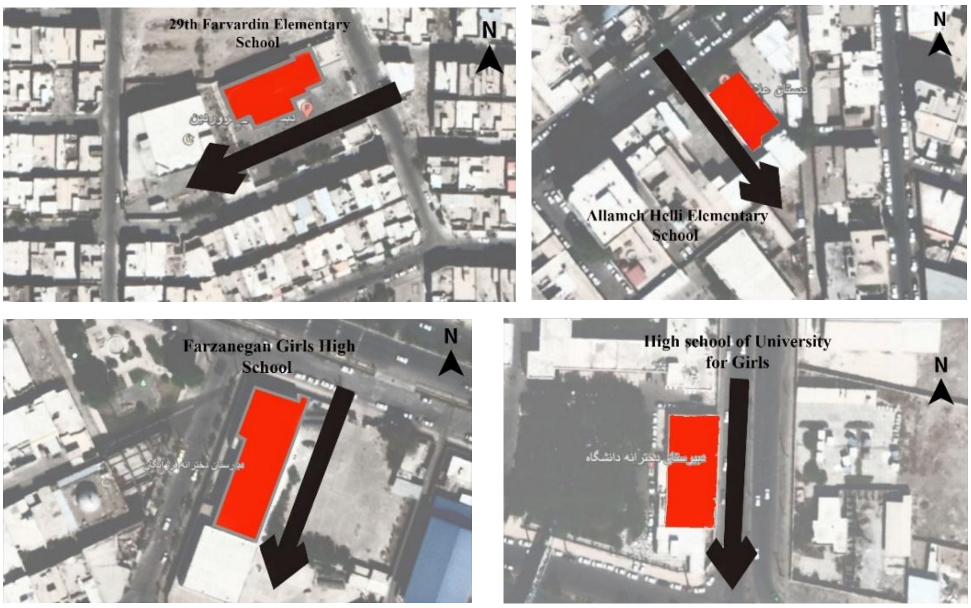


Fig. 1. Building orientation of the four exemplar schools in *Zahedan*-iran. (Authors)

Design Builder was validated experimentally by comparing the simulation results to the field measurements and comparatively by comparing the results from energy simulators by two researchers in the climate in Iran. They modeled an academic building in Kashan city using Design-Builder and Ecotect to calculate the building total annual energy consumption through simulations. They also compared the results to the actual annual energy consumption data (based on the bills). Their findings showed a great similarity between the Design-Builder results and operating conditions (Zomorodian & Tahsildoost, 2015). In Iran, some researchers have used this software to simulate and compare energy consumption and natural ventilation in office buildings in Rasht due to changes in the ratio of window to wall. (Sedigh Ziabari et al., 2019)
After comparing the results from different energy simulation methods and software with the actual annual energy consumption in a single-household residential building in a Mediterranean region based on the bills, Tronchin and Fabbri found that Design-Builder produced the closest results to the operating ratings (Tronchin & Fabbri, 2008: 1185). Therefore, the research findings revealed that Design-Builder could be effective for the data in the present study.

### 3.3 Location and Climate Type

Kopen's method is one of the methods proposed and approved for the climatic classification of regions. It was first developed by a Russian scientist called W. Kopen[v] in 1884, who introduced five climates on a vegetation-based global scale: A (tropical), B (dry), C (temperate), D (continental) and E(polar) Later, the climatologist R. Geiger[vi] introduced some changes to the classification system, which is thus sometimes called the Köppen–Geiger climate classification system.
Iran is a high plateau located at latitude $25-40°N$, and thus it is generally considered a hot region. The following climate zoning is proposed for Iran: 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 coats) (Kasmaee, 2003: 82). *Sistan and Baluchestan* province is situated at the south east of the Iranian Plateau at latitude $25^0$ 4′ to $31^0$ 29′ N and longitude $58^0$50′ to $63^0$19′ E .The surface area of this province is also 181785 km$^2$ which is equal to 11% of the whole country area (Iran's Statistical Yearbook, 2018:53). According to the 2016 Housing and Population Census, the population of this province is 2775014 persons. Of these, 1427332 live in rural areas. (Ibid: 140) There are a lot of remote rural areas in the province where service delivery proves to be considerably difficult.
In sum, this province has an arid and hot climate. In this climate, extremely dry air is breathed due to the flow of winds blowing from the southwest and northwest to the equator. The temperature variation is high in these regions, and there is an approximately $20\,°C$ difference between the lowest and highest temperature (Kasmaee, 2003: 84).

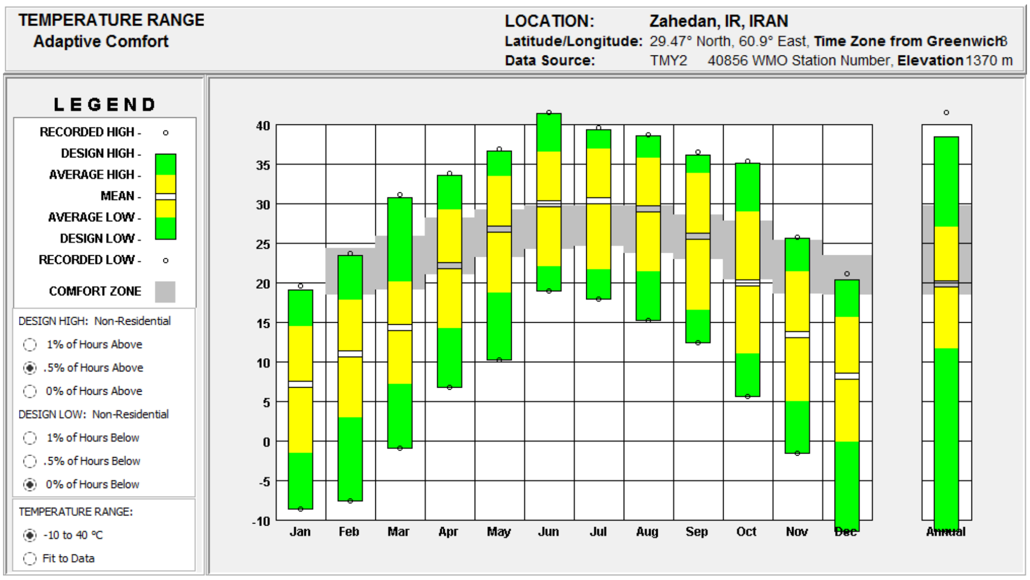



Fig. 2.Temperature Range of *Zahedan* (Authors, Based on climate consultant software output)

*Zahedan* the capital of province has a hot and arid climate and is located at altitude 1370m, at latitude $29^0$28′, and longitude $60^0$52′. The average number of frost days is 57.9, while the average precipitation reported from 1951 to 1975 was 109.5 mm. The maximum daily precipitation was also 62mm in January (Kasmaee, 2003: 262).

Moreover, according to the 2016 Housing and Population Census, the population of *Zahedan* is 587730 (Iran Statistical Yearbook, 2018:148). The population growth in *Zahedan* is noticeable in comparison to other provincial capitals in Iran, which points to the importance of this study.

### *3.4 Weather data*

The lowest average monthly temperature in *Zahedan* in the last 20 years is 2 °C in January 2008, and its highest value is 31.6 °C which was reported in July 2006 (irimo.ir). In addition, the annual average temperature of 60 years from 1951-2014 has been reported 18.6 °C (Iran Statistical Yearbook, 2018:69). The average of annual maximum relative humidity is also 49.3% and the average of minimum is 18.3%. (Ibid: 69) The average annual maximum wind speed is 11.86 m/s (Kasmaee, 2003: 146) Wind mostly blows from south east and the annual average outdoor wind speed (WS) is approximately 3.35 m/s. Table (2) (in appendix) presents the monthly climatic data in *Zahedan*.

Figure 3 shows the Wind-Rose of *Zahedan*. Three parameters shown in this chart are wind speed, wind direction, and the frequency of the wind. As can be seen, 10.97% of the whole time of the year, which is equivalent to 961 hours, is calm.

Table 2

Monthly climatic data of *Zahedan* (Source: Authors)

| Month | Jan | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Outside Dry-Bulb Temperature($^0$C) | 7.16 | 11.07 | 14.31 | 22.24 | 26.78 | 29.95 | 30.35 | 29.38 | 25.84 | 19.95 | 13.47 | 8.14 |
| Outside Dew-Point Temperature($^0$C) | -6.47 | -4.55 | -3 | -3.81 | -4.78 | -7.68 | -4.81 | -2.09 | -4.7 | -3.78 | -1.95 | -3.86 |
| Wind Speed(m/s) | 3.18 | 4.46 | 4.44 | 3.15 | 3.18 | 3.46 | 3.64 | 3.04 | 2.98 | 2.36 | 2.90 | 3.46 |
| Wind Direction($^0$) | 157.8 | 173.6 | 172.22 | 148.12 | 111.2 | 148.20 | 162.68 | 137.66 | 125.00 | 169.81 | 169.85 | 162.34 |
| Atmospheric Pressure(Pa) | 86412 .23 | 86468. 9 | 86146. 37 | 86105 | 85944. 76 | 85733. 05 | 85605. 78 | 85589. 78 | 86033. 61 | 86418. 68 | 86544. 16 | 86487. 91 |
| Direct Normal Solar(kWh) | 146. 633 | 152. 097 | 178. 409 | 199. 788 | 208. 993 | 203. 322 | 207. 407 | 199.07 | 181. 948 | 164. 082 | 150. 845 | 149. 121 |
| Diffuse Horizontal Solar(kWh) | 45. 234 | 45.749 | 61.528 | 60.75 | 71.661 | 75.689 | 78.418 | 87.535 | 80.934 | 74.609 | 50.599 | 44.286 |

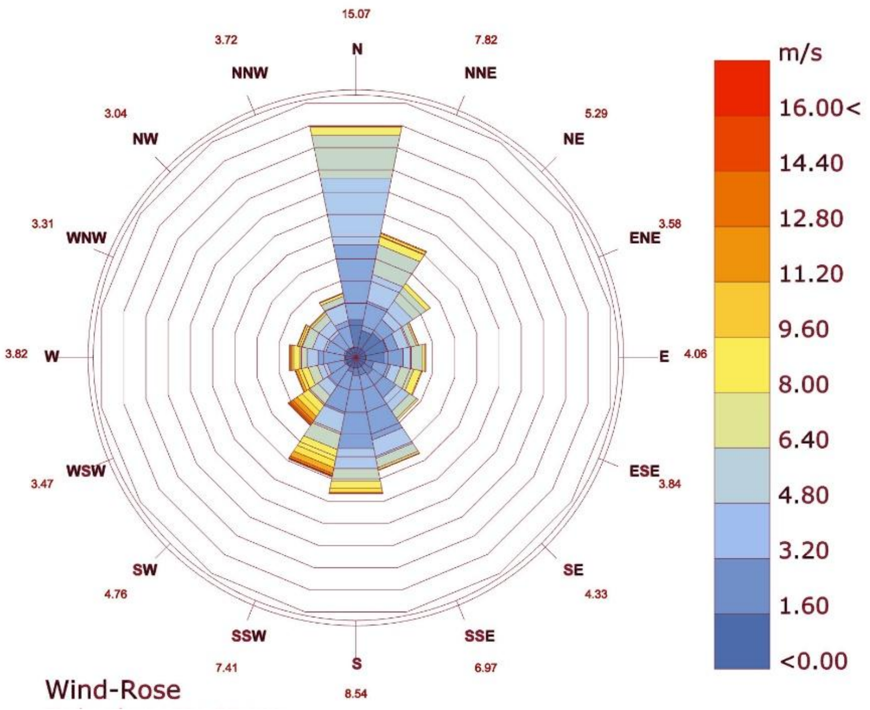



Fig. 3. The Wind-Rose of *Zahedan* 1 JAN 1:00 -31 DEC 24:00 (Ladybug plugin output, Rhinoceros Software)
Each closed polyline shows frequency of 1.5%=132 hours, Hourly Data: Wind Speed (m/s)

The outdoor hourly weather data as one of the most important parameters were used to explain the interior temperature and the energy required for thermal comfort. To prepare the hourly climatic file in the epw format for *Zahedan*, the data measured from 1997 to 2017 by the Iran Meteorological Organization as the only reliable source of data were analyzed. The data provided by the Iran Meteorological Organization are available for every three hours. However, to prepare ITMY or epw files it is necessary to provide hourly data after selecting the related months in a given year. Therefore, Lagrange's interpolation formula was used for the three reported data to obtain the missing data related to every two hours.

| Hours<br>( from the first day) | Parameter values | Hours | Parameter values | Hours | Parameter values |
|---|---|---|---|---|---|
| 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 do this, first, all the available data (the bolded data in the table) were arranged in a table in an hourly order (from 1 to 8760). Then, the missing data (the non-bolded data in the table) were calculated from the three available data by using the Lagrange's interpolation formula. For example, to determine the values of F4 and F5 data, the F3, F6, and F9 data were interpolated. Similarly, to calculate the values of F7 and F8 data, the F6, F9, and F12 data were interpolated. Finally, to find out the values of F7 and F8 data, the F3, F6 and F8760 data were interpolated. The Lagrange's interpolation formula is run on the three datasets as follows:

| **X** | $\mathbf{X_0}$ | $\mathbf{X_1}$ | $\mathbf{X_2}$ |
|---|---|---|---|
| **F** | $F_0$ | $F_1$ | $F_2$ |

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

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

Charts 3 to 6 present the daily temperature, wind, barometric pressure, and solar radiation data in *Zahedan*.

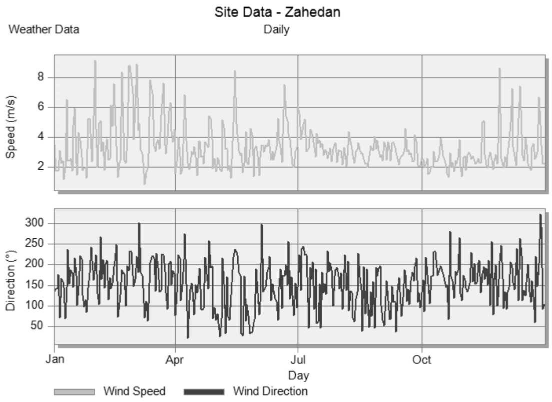



Fig. 4. Daily wind speed and direction in *Zahedan*

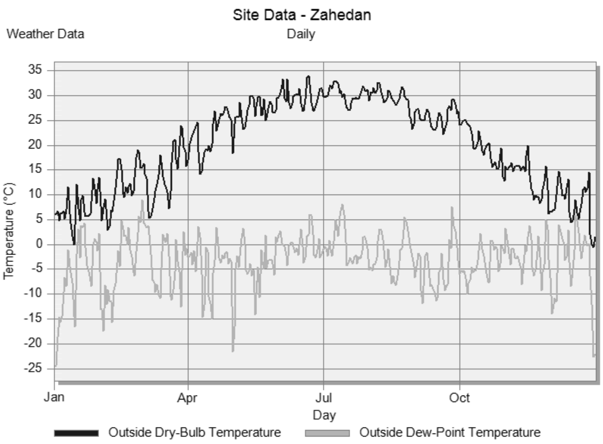



Fig. 5. Daily weather data of *Zahedan*

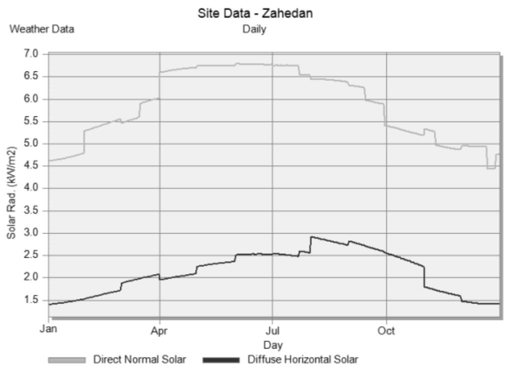



Fig. 6. Daily radiation data of *Zahedan*

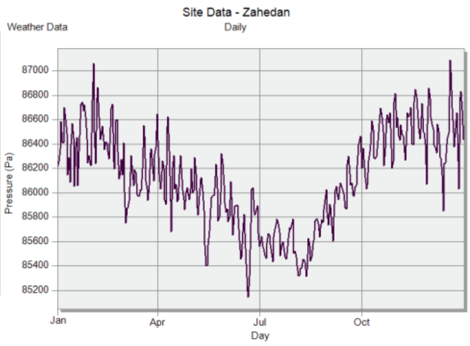



Fig. 7. Daily Atmospheric pressure in *Zahedan*

*3.5 The Study Building*

A small-sized building was selected in this study. The reason for selecting this building was that its plan is used commonly to construct buildings in hot and arid villages as well as distant areas in Iran, and when it multiplies, a small reduction in energy consumption will result in considerable energy saving.

The case is a two-classroom one-storey school building with a total surface area of 72.36 square meters. The building plan is used as a model in the hot and arid areas in Iran. Figures 8 - 10 show two classrooms with a surface area of 23.50 square meters, including a teachers office with a surface area of 7.80 square meters and two bathrooms with a surface area of 1.3 square meters. The difference between the whole area of the building and the total area of the spaces is related to the thickness of the walls. The distance between the floor and the top of roof is 340 cm. The window to wall ratio (WWR) in the classrooms is 18% on the north and south sides with an east-west orientation (the photographed example). The eastern and western walls of the classrooms also have no window.

Fig. 8. Iran-e-Man School Number 50, a sample building built based on the studied plan, in a village near *Zahedan*, in the hot and arid region in Iran (Authors)

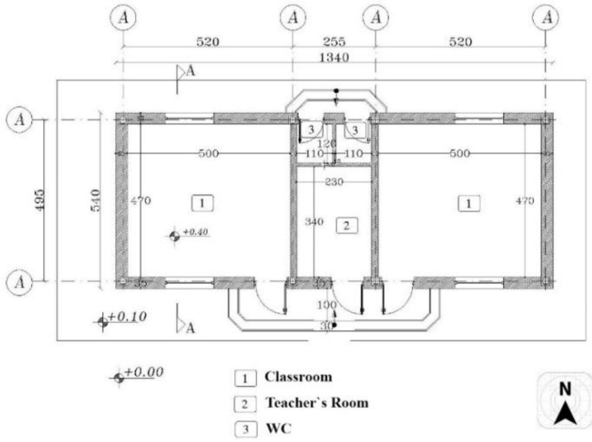



Fig. 9. Ground floor plan

(Source: Archive of Organization for Development, Renovation and Equipping Schools**)**

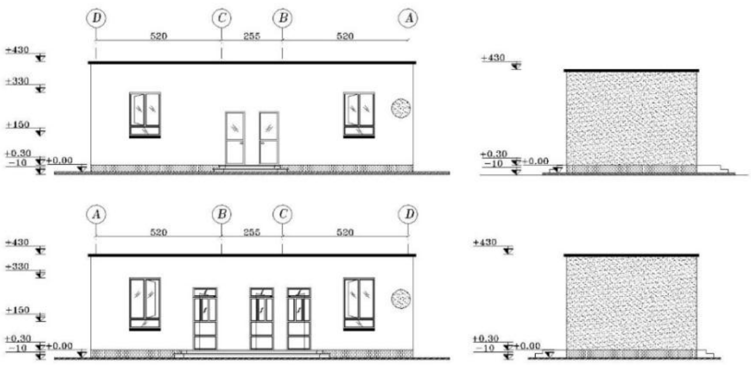



Fig. 10. Elevations (Source: Ibid).

Table (3) presents the information for the occupant densities, fresh airflow rate, and equipment densities in accordance with the ASHRAE standard (ASHRAE, 2007, 2009).

Table 3
The related spaces and information (Source: Authors)

| Zone Name | Floor Area($m^2$) | Zone Volume($m^3$) | Occupancy (people/$m^2$) | Lighting (lux) | Equipment (W/$m^2$) | Fresh Air (L/s-person) |
|---|---|---|---|---|---|---|
| **Classroom 1** | 23.50 | 72.25 | 0.875 | 300 | 4.70 | 5.5 |
| **Classroom2** | 23.50 | 75.12 | 0.875 | 300 | 4.70 | 5.5 |
| **Teacher`s Room** | 7.80 | 24.65 | 0.23 | 200 | 18.54 | 10 |
| **WC1** | 1.29 | 3.98 | 0.1124 | 150 | 5.48 | 12 |
| **WC 2** | 1.29 | 3.98 | 01124 | 150 | 5.48 | 12 |

*3.5.1 Construction*

The plans, details, wall materials, roofs, and other parts of the building were provided by *Organization for Development, Renovation and Equipping Schools*. This organization is responsible for building schools in rural areas in Iran. Since ceiling layers and thermal wall insulations are not generally used in buildings constructed in rural areas in the country, the data for actual conditions and materials were used in this paper, because our goal is 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, etc. are the subjects of the future studies.

*3.5.1.1 External Walls*

The existing external walls in the building are made by a face brick layer, a cement sand mortar layer, a brick layer, and an interior gypsum wall with no thermal insulation. Figure 11 shows the cross-section of an actual wall in the building. The U-value of this wall type is 1/756(W/$m^2$-K).

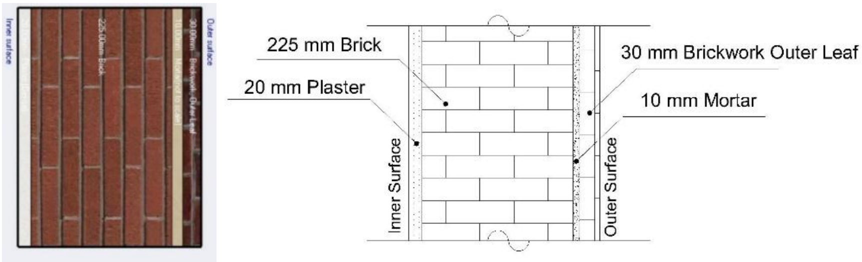



Fig. 11. External walls details (Authors)

*3.5.1.2 Internal Partitions*

The internal partitions are composed of two layers of gypsum plasterboard with a thickness of 2.5 cm with a 10 cm layer of air in between. The U-value of these walls is 1.639 (W/$m^2$-K).

*3.5.1.3 Roof*

The building actual roofs consist of the following layers from top to bottom: asphalt, sand cement mortar, tar paper bitumen (Bitumen and sack) layers as moisture insulation, expanded slag for drainage gradient, bar joists and clay blocks ceiling and stucco as shown in Figure 12. As it can be seen, no thermal insulation has been used in this ceiling and the calculated U-value is 0.570 (W/$m^2$-K).

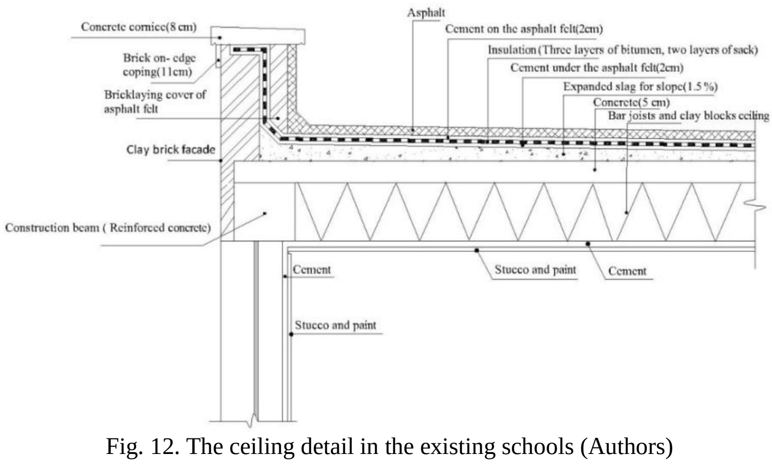



Fig. 12. The ceiling detail in the existing schools (Authors)

*3.5.1.3 Glazing Type and Lighting*

Insulated glazing with a thickness of 6 mm has been used in the building with a 13-mm intermediary air layer (U-value=2.785 (W/m$^2$-K)). SHGC[vii] is 0.497. Table (4) shows the properties of the glazing used in the simulation.

Table 4
Glazing properties (Source: Authors)

| **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 |

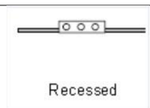
The frames used in the models are made of aluminum plates with a thickness of 2 mm, and a PVC[viii] layer is used in between as thermal break with a thickness of 5 mm. The U-value of this window frame is also 4.719 (W/m$^2$-K).

Based on the research results, 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 teachers office and bathrooms equals 200 lux and 150 lux, respectively (Rea, 2000) (Mahlabani et al., 2011). The lighting density for different rooms is shown in Table (3). LED lights with linear control have been used to ease the lighting shortage at hours when there is little daylight or it is cloudy. The radiation fraction[ix] of the lights is 0.37 and the visible fraction[x] of these lights is 0.18. The normalized power density is also 2.5 (W/m$^2$-100 lux). The lighting linear control is assumed for the lights and the radiation is automatically adjusted to only compensate the lighting shortage relative to daylight. Table (5) lists the specifications of the mentioned lights.

*3.5.1.4 Shadings*

Using shadings is an effective strategy for reducing the energy required for cooling the building in hot and arid climates. To provide the required daylight to the classrooms, almost large windows are used, and it is important to shade them to block solar radiation during the hot months. Hence, in the simulation models, an overhang projection is placed on the top and two side fin projections are placed on both sides of each window. These shadings are made of natural rubber with a thickness of 1 cm. The lengths of the overhang projection and the side fins projection are 70 and 30 cm, respectively.
The details of the wall, ceiling, and glazing used in the simulations, and the U-values of each are listed in Appendix, Table (6) and (7). The optimum specifications of the glazing, window profiles, and the size, and shape of the shadings required for maximum annual energy efficiency are the subjects of the future studies. The same shadings and glazing are used in this study for all models, and considering the comparison results, these parameters do not influence the final results. This is because the main goal of this study is to find the best orientation.

Table 5
Light specifications (Source: Authors)

| **LED with linear control** | |
|---|---|
| Normalized power density (W/m$^2$-100 lux) | **2.50** |
| Luminaire type |   |
| Radiant fraction | **0.37** |
| Visible fraction | **0.18** |

*3.6 Simulation parameters*

*3.6.1 Occupancy Schedule*

Given the yearly curricula of Iranian schools, especially in tropical areas, the daily occupancy of the building and the yearly HVAC schedules cannot be calculated using standards such as ASHRAE. Schools in the rural tropical regions of Iran are usually open from Saturday to Wednesday from 7 AM. to 17 PM. However, during June, July, August, and September, the schools are closed. During these four months, the HVAC systems are turned off and minimum lighting is required in the buildings. In other months, the school buildings are closed after 17 PM and on Thursdays and Fridays. Hence, minimum lighting and thermal requirements are predicted depending on the heating/cooling setback temperature.

*3.6.2 Heating and Cooling Schedule*

In the design of buildings, the mental comfort of the occupants, which results from various factors such as adequate temperature, humidity, and airspeed, is known as thermal comfort. Most researchers believe "thermal neutrality" is a more precise description of thermal comfort. It refers to a condition in which the residents do not feel cold, hot, or irritated by asymmetrical radiation, cross ventilation, a cold room floor, heterogeneous clothes, etc. (Watson & Labs, 2010: 29).

Figure 13 shows the Psychometric chart of educational environments in *Zahedan*. As it can be seen in 16% of the whole year, which is equal to 1401 hours, there is thermal comfort situation in the building, especially classrooms without any uses of HVAC systems.

Table 6
The wall and roof properties used in the simulation. (Source: Authors)

| | **Roof** | **External walls** | **External window frames** |
|---|---|---|---|
| Inner surface | | | |
| Convective heat transfer coefficient(W/m$^2$-K) | 3.805 | 2.152 | **2.152** |
| Radiative heat transfer coefficient(W/m$^2$-K) | 5.540 | 5.540 | **5.540** |
| Surface resistance(m$^2$-K/W) | 0.107 | 0.130 | **0.130** |
| **Outer surface** | | | |
| Convective heat transfer coefficient(W/m$^2$-K) | 28.203 | 19.870 | **23.290** |
| Radiative heat transfer coefficient(W/m$^2$-K) | 5.130 | 5.130 | **1.710** |
| Surface resistance(m$^2$-K/W) | 0.030 | 0.040 | **0.040** |
| **No bridging** | | | |
| U-Value surface to surface (W/m$^2$-K) | 0.618 | 2.442 | **23.853** |
| R-Value(m$^2$-K/W) | 1.754 | 0.580 | **0.212** |
| U-Value(W/m$^2$-K) | 0.570 | 1.725 | **4.719** |
| **With Bridging (BS EN ISO 6946)** | | | |
| Thickness(m) | 0.0682 | 0.2850 | **0.009** |
| Km-Internal heat capacity(KJ/m$^2$-K) | 195.088 | 149.0240 | **3.9675** |
| Upper resistance limit(m$^2$-K/W) | 3.323 | 0.580 | **0.212** |
| Lower resistance limit(m$^2$-K/W) | 3.323 | 0.580 | **0.212** |
| U-Value Surface to surface(W/m$^2$-K) | 0.314 | 2.442 | **23.853** |
| R-Value(m$^2$-K/W) | 3.323 | 0.580 | **0.212** |
| U-Value(W/m$^2$-K) | 0.301 | 1.725 | **4.719** |

Table 7
Materials layers used in the building and the calculated u-values. (Source: Authors)

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

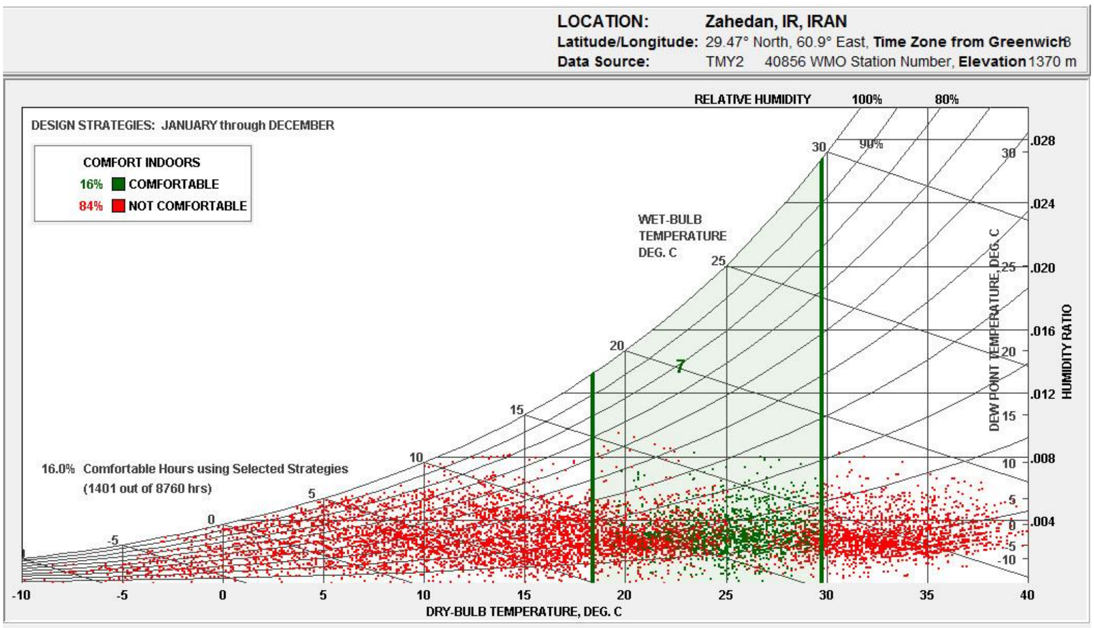



Fig. 13. Psychometric Chart of educational environments in *Zahedan*
(Authors, based on climate consultant software output)

The researchers from Kansas University concluded that people that wear office uniforms are most satisfied with an environment at a dry-bulb temperature 79 $°F$, relative humidity of 50%, and airspeed of below 35 feet per minute (ASHRAE, 1981). In sum, thermal comfort is contingent upon numerous factors such as temperature, humidity, airspeed, clothing, and average radiation temperature. Since there is no approved standard in *Zahedan*, the yearly HVAC schedule is presented based on the weather data as follows:

Tables (8) and (9) show the maximum and minimum monthly temperatures in *Zahedan* from 2013 to 2017. To make a decision on the HVAC schedule, the mean of the 5 figures listed in the two tables above is calculated and listed in Table (10). The analysis of the resulting information in Figure 13 reveals that the cooling function is only required during April, May, and October. The heating function is also not needed during May. From June to September, when the school building is not occupied during the summer holidays, the HVAC systems are completely turned off.

Table 8
Maximum monthly temperature (2013-2017) in *Zahedan* (Source: irimo.ir)

| Year | Jan | | Feb | | March | | April | | May | | June | | Jul | | August | | Sep | | Oct | | Nov | | Dec | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Day | T (◦c) | Day | T (◦c) | Day | T (◦c) | Day | T (◦c) | Day | T (◦c) | Day | T (◦c) | Day | T (◦c) | Day | T(◦c) | Day | T (◦c) | Day | T (◦c) | Day | T (◦c) | Day | T (◦c) |
| **2013** | 25 | 21.3 | 8 | 23 | 17 | 28.9 | 14 | 32 | 31 | 38.4 | 26 | 41.8 | 28 | 41.6 | 9 | 39.4 | 24 | 37.5 | 7 | 36 | 13 | 24.9 | 15 | 25.2 |
| **2014** | 29 | 23 | 17 | 20.2 | 31 | 25.8 | 28 | 35.4 | 29 | 39 | 13 | 42 | 28 | 42.7 | 10 | 39.1 | 24 | 37.4 | 5 | 35.6 | 4 | 27.8 | 17 | 22.9 |
| **2015** | 30 | 25.4 | 13 | 28.2 | 31 | 30.2 | 25 | 37 | 15 | 39.2 | 27 | 40.2 | 4 | 40 | 24 | 40.6 | 10 | 35.3 | 10 | 35.4 | 10 | 25.8 | 3 | 27.6 |
| **2016** | 25 | 24.4 | 25 | 29.2 | 28 | 29 | 29 | 34.8 | 17 | 39.5 | 13 | 41.5 | 4 | 41.5 | 9 | 37.6 | 26 | 38.3 | 18 | 31.8 | 17 | 28.5 | 28 | 28.6 |
| **2017** | 2 | 26.4 | 1 | 22.3 | 31 | 28.8 | 16 | 36.2 | 25 | 40.6 | 23 | 43.4 | 8 | 40.7 | 10 | 38 | 4 | 36.1 | 3 | 36 | 1 | 30 | 25 | 26.1 |
| **Average** | | 24.10 | | 24.58 | | 28.54 | | 35.08 | | 39.34 | | 41.78 | | 41.3 | | 38.94 | | 36.92 | | 34.96 | | 27.4 | | 26.08 |

Table 9
Minimum monthly temperature (2013-2017) in *Zahedan*. (Source: irimo.ir)

| Year | Jan | | Feb | | March | | April | | May | | June | | Jul | | August | | Sep | | Oct | | Nov | | Dec | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Day | T (◦c) | Day | T (◦c) | Day | T (◦c) | Day | T (◦c) | Day | T (◦c) | Day | T (◦c) | Day | T (◦c) | Day | T(◦c) | Day | T (◦c) | Day | T (◦c) | Day | T (◦c) | Day | T (◦c) |
| **2013** | **18** | **-9.1** | **6** | **-1.7** | **10** | **1.5** | **2** | **7** | **10** | **12.5** | **18** | **13.8** | **10** | **16.5** | **17** | **14** | **5** | **11.7** | **27** | **5.4** | **7** | **1.2** | **31** | **-13** |
| **2014** | **1** | **-9.8** | **4** | -7.6 | **11** | **-0.7** | **7** | **6.4** | **18** | **11.2** | **3** | **17.2** | **20** | **14.6** | **17** | **13.8** | **15** | **11** | **14** | **4.2** | **10** | **-2.4** | **27** | **-5.9** |
| **2015** | **15** | **-6.9** | **28** | **-2.6** | **1** | **-2.3** | **7** | **8.4** | **11** | **13.2** | **11** | **13** | **8** | **17.6** | **17** | **14.1** | **27** | **7** | **27** | **5.6** | **28** | **-2.6** | **12** | **-8.4** |
| **2016** | **19** | **-4.9** | **11** | **-5.4** | **4** | **3.6** | **3** | **5.2** | **4** | **13.1** | **16** | **16** | **20** | **18.4** | **28** | **13.2** | **25** | **13.2** | **27** | **4** | **27** | **-2.9** | **13** | **-3.6** |
| **2017** | **8** | **-7.8** | **5** | **-3.4** | **11** | **-1** | **6** | **3.2** | **3** | **14.2** | **8** | **15** | **18** | **16** | **27** | **13.4** | **25** | **9.6** | **27** | **6.8** | **21** | **-2.7** | **5** | **-11.40** |
| **Average** | | **-7.7** | | **4.14** | | **0.22** | | **6.04** | | **12.84** | | **15** | | **16.62** | | **13.7** | | **10.50** | | **5.2** | | **-1.88** | | **-8.46** |

Table 10
Heating and Cooling Schedule Analysis in *Zahedan* (Source: Authors)

| | **Jan** | **Feb** | **March** | **April** | **May** | **June** | **Jul** | **August** | **Sep** | **Oct** | **Nov** | **Dec** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Max av temp** | 24.10 | 24.58 | 28.54 | 35.08 | 39.34 | 41.78 | 41.3 | 38.94 | 36.92 | 34.96 | 27.4 | 26.08 |
| **Min av temp** | -7.7 | 4.14 | 0.22 | 6.04 | 12.84 | 15 | 16.62 | 13.7 | 10.50 | 5.2 | -1.88 | -8.46 |
| **Heating** | + | + | + | + | - | - | - | - | - | + | + | + |
| **Cooling** | - | - | - | + | + | - | - | - | - | + | - | - |

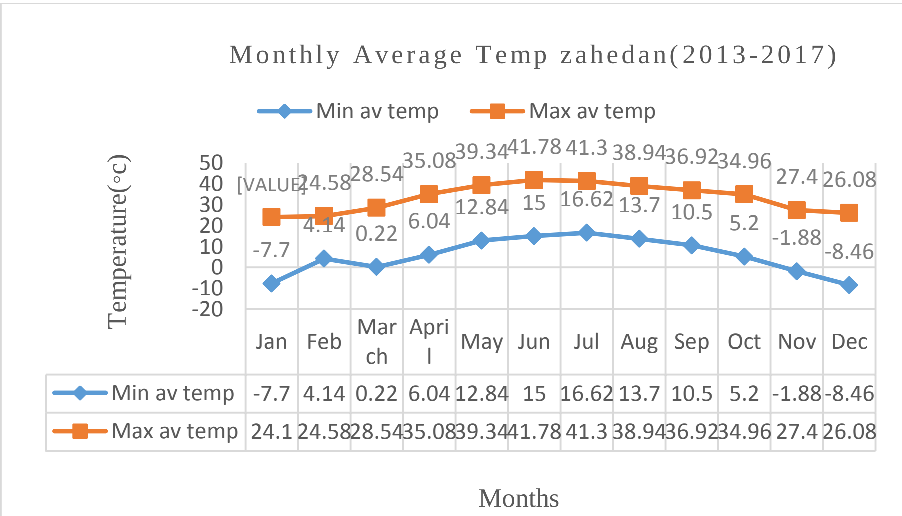



Fig. 14. Monthly average temperature in *Zahedan* (Source: irimo.ir)

*3.6.3 HVAC Systems*

Since reducing the risk of fire in school buildings is necessity and the buildings may be constructed in distant areas, Split with natural ventilation systems are utilized to provide thermal comfort in the models. This system receives electricity from the grid (transport of other fuels to the location may be difficult). Besides, the heating and cooling system seasonal CoP[xi] are equal to 2.35 and 1.83, respectively. It is worth mentioning that the goal of this study is to find the optimum orientation by comparing different models, while the HVAC system efficiency does not affect the outcome. The heating and cooling temperatures required in this building for providing thermal comfort are 21 and 24 $°C$ , respectively. Finally, the heating setback temperature is12 $°C$ .

## 4. Methodology

To find the best building orientation suiting *Zahedan*climate, the computer simulation of the building was carried out with the aforesaid properties. Figure.15 shows the simulated building image on November 15, 10 AM.

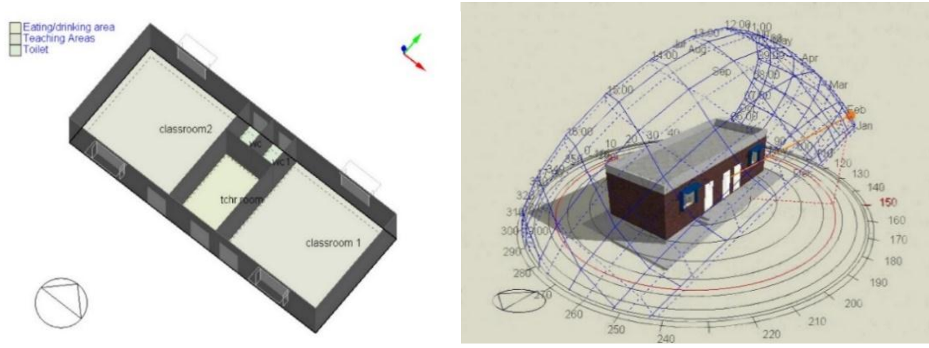



Fig .15. The simulated building image on November 15, 10 AM (Authors)

Then, the longitudinal axis of the model was rotated clockwise with 5-degree intervals and for each model, simulation was performed and the results were recorded.Figures 16 and 16 show this type of rotation of the models.

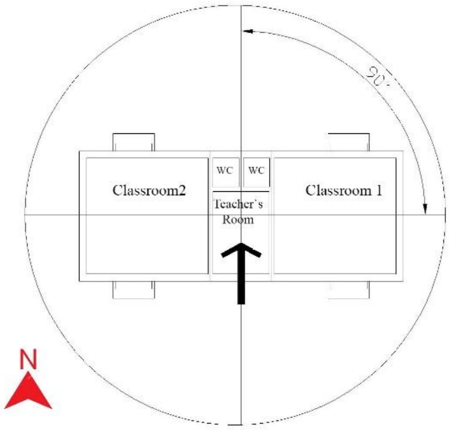



Fig. 16. Model No.19 with East-to-west orientation (Longitudinal axis angle of 90)

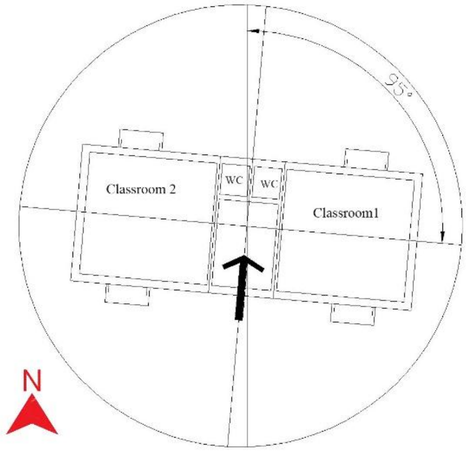



Fig. 17. Model No. 20, with 5-degree rotation (Longitudinal axis angle of 95)

Totally 72 models were obtained and the energy simulation was carried out for each model. The total annual fuel consumption, total annual energy consumption for heating and cooling, the total electricity consumption of equipment and lighting systems, and the total annual energy consumption were recorded in kWh (Table 12).

The 90-degree orientation angle refers to a building position on the site in which the longitudinal axis is located along with east-west direction and the classroom doors are on the southern side (model 19). Figure 18 to 21 show the monthly energy consumption, fuel breakdown, internal gains and $co_2$ production of this simulated model.

Table 12

Building energy consumption in 72 simulated models, 1Jan -31 Dec. (Source: Authors)

| Model Num. | Longitude Axis Angle | Lighting and Room electricity(kWh) | District cooling(kWh) | District Heating (kWh) | Total Energy consumption (kWh) |
|---|---|---|---|---|---|
| **1** | 0 | 1411.34 | 2820.61 | 1905.51 | 5371.098 |
| **2** | 5 | 1410.85 | 2820.51 | 1910.69 | 5376.788 |
| **3** | 10 | 1411.65 | 2820.14 | 1914.42 | 5381.86 |
| **4** | 15 | 1412.10 | 2818.32 | 1917.48 | 5384.902 |
| **5** | 20 | 1412.74 | 2814.14 | 1922.05 | 5388.55 |
| **6** | 25 | 1412.96 | 2809.89 | 1925.00 | 5389.773 |
| **7** | 30 | 1414.15 | 2806.48 | 1925.90 | 5390.006 |
| **8** | 35 | 1414.34 | 2799.86 | 1927.84 | 5388.568 |
| **9** | 40 | 1413.26 | 2796.27 | 1924.73 | 5381.595 |
| **10** | 45 | 1412.48 | 2789.35 | 1925.23 | 5377.272 |
| **11** | 50 | 1412.86 | 2784.96 | 1920.82 | 5369.707 |
| **12** | 55 | 1412.28 | 2780.04 | 1912.74 | 5356.455 |
| **13** | 60 | 1412.67 | 2774.31 | 1904.05 | 5342.937 |
| **14** | 65 | 1412.02 | 2768.14 | 1896.08 | 5328.995 |

| | | | | | |
|---|---|---|---|---|---|
| **15** | 70 | 1411.57 | 2764.09 | 1885.25 | 5313.067 |
| **16** | 75 | 1413.54 | 2762.46 | 1872.93 | 5299.219 |
| **17** | 80 | 1413.50 | 2759.61 | 1861.97 | 5284.268 |
| **18** | 85 | 1415.19 | 2758.33 | 1852.88 | 5274.233 |
| **19** | 90 | 1415.86 | 2759.52 | 1841.52 | 5262.173 |
| **20** | 95 | 1415.70 | 2762.09 | 1834.90 | 5255.333 |
| **21** | 100 | 1416.67 | 2764.66 | 1831.05 | 5253.208 |
| **22** | 105 | 1417.27 | 2769.19 | 1827.93 | 5252.756 |
| **23** | 110 | 1416.99 | 2775.34 | 1825.11 | 5252.773 |
| **24** | 115 | 1416.98 | 2781.13 | 1825.16 | 5256.282 |
| **25** | 120 | 1417.50 | 2787.67 | 1827.47 | 5263.496 |
| **26** | 125 | 1417.22 | 2791.93 | 1833.11 | 5272.563 |
| **27** | 130 | 1416.64 | 2800.23 | 1832.39 | 5276.088 |
| **28** | 135 | 1418.16 | 2805.00 | 1836.84 | 5285.825 |
| **29** | 140 | 1416.54 | 2809.93 | 1842.02 | 5293.407 |
| **30** | 145 | 1416.60 | 2814.69 | 1846.87 | 5302.154 |
| **31** | 150 | 1414.90 | 2818.28 | 1852.65 | 5309.566 |
| **32** | 155 | 1414.35 | 2820.44 | 1860.07 | 5319.255 |
| **33** | 160 | 1414.28 | 2822.36 | 1866.16 | 5327.668 |
| **34** | 165 | 1413.26 | 2824.56 | 1873.45 | 5336.742 |
| **35** | 170 | 1412.55 | 2825.29 | 1879.59 | 5343.877 |
| **36** | 175 | 1411.82 | 2825.14 | 1888.20 | 5353.431 |
| **37** | 180 | 1412.08 | 2823.43 | 1895.90 | 5361.941 |
| **38** | 185 | 1410.89 | 2822.51 | 1901.59 | 5367.055 |
| **39** | 190 | 1411.34 | 2820.09 | 1909.62 | 5375.731 |
| **40** | 195 | 1411.38 | 2816.41 | 1915.73 | 5380.932 |
| **41** | 200 | 1411.61 | 2812.12 | 1920.16 | 5383.925 |
| **42** | 205 | 1411.55 | 2806.88 | 1925.43 | 5387.075 |
| **43** | 210 | 1412.16 | 2800.71 | 1930.21 | 5389.75 |
| **44** | 215 | 1411.50 | 2792.89 | 1932.47 | 5387.135 |
| **45** | 220 | 1410.63 | 2786.08 | 1933.80 | 5383.783 |
| **46** | 225 | 1410.16 | 2778.29 | 1935.95 | 5381.238 |
| **47** | 230 | 1408.85 | 2770.50 | 1934.65 | 5373.707 |
| **48** | 235 | 1409.47 | 2763.09 | 1929.79 | 5364.03 |
| **49** | 240 | 1408.35 | 2756.05 | 1923.26 | 5350.827 |
| **50** | 245 | 1408.28 | 2748.91 | 1916.29 | 5338.084 |
| **51** | 250 | 1408.50 | 2743.00 | 1906.83 | 5323.364 |
| **52** | 255 | 1409.24 | 2739.47 | 1897.69 | 5310.988 |
| **53** | 260 | 1408.75 | 2736.31 | 1886.33 | 5294.912 |
| **54** | 265 | 1410.38 | 2734.63 | 1879.95 | 5287.852 |
| **55** | 270 | 1411.71 | 2735.67 | 1870.18 | 5278.036 |
| **56** | 275 | 1411.20 | 2738.16 | 1862.74 | 5270.044 |
| **57** | 280 | 1412.16 | 2740.09 | 1860.35 | 5269.291 |
| **58** | 285 | 1412.23 | 2746.64 | 1855.81 | 5267.804 |
| **59** | 290 | 1412.95 | 2751.63 | 1855.69 | 5271.374 |
| **60** | 295 | 1412.35 | 2758.21 | 1855.98 | 5275.066 |
| **61** | 300 | 1412.80 | 2766.00 | 1856.41 | 5280.693 |
| **62** | 305 | 1412.32 | 2772.95 | 1858.72 | 5287.163 |
| **63** | 310 | 1412.50 | 2780.31 | 1860.87 | 5294.335 |
| **64** | 315 | 1413.17 | 2786.64 | 1865.48 | 5304.353 |
| **65** | 320 | 1411.82 | 2793.05 | 1868.75 | 5310.775 |
| **66** | 325 | 1411.89 | 2798.83 | 1872.36 | 5318.656 |
| **67** | 330 | 1412.19 | 2805.07 | 1875.83 | 5326.87 |
| **68** | 335 | 1412.49 | 2808.40 | 1881.22 | 5335.665 |
| **69** | 340 | 1412.04 | 2812.60 | 1884.30 | 5341.443 |
| **70** | 345 | 1412.48 | 2816.10 | 1889.07 | 5349.726 |
| **71** | 350 | 1411.57 | 2818.23 | 1895.77 | 5358.156 |
| **72** | 355 | 1411.62 | 2819.37 | 1901.38 | 5365.656 |

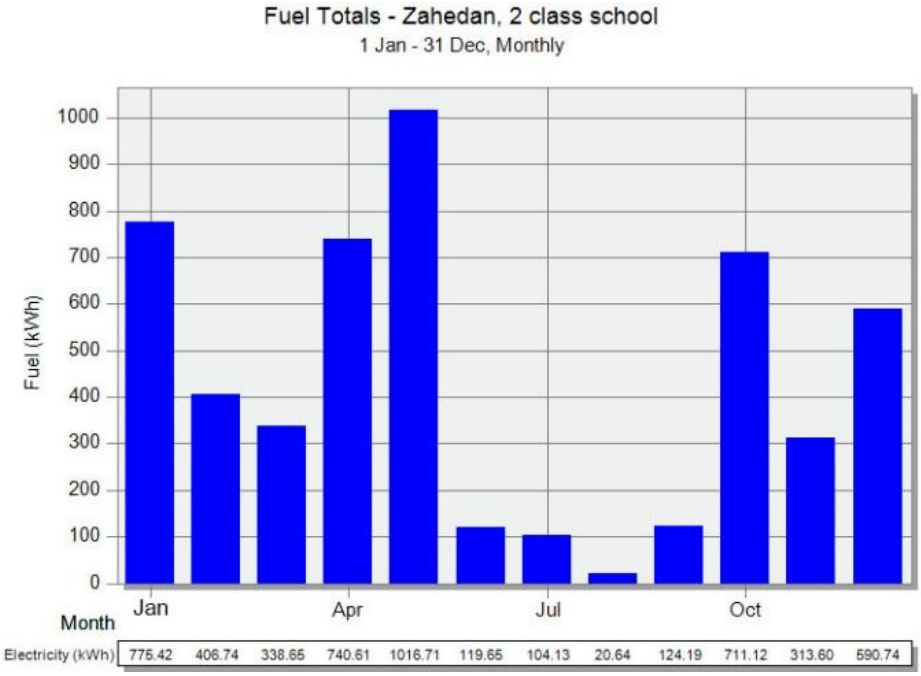



Fig. 18. Monthly Energy Consumption, Model No.19

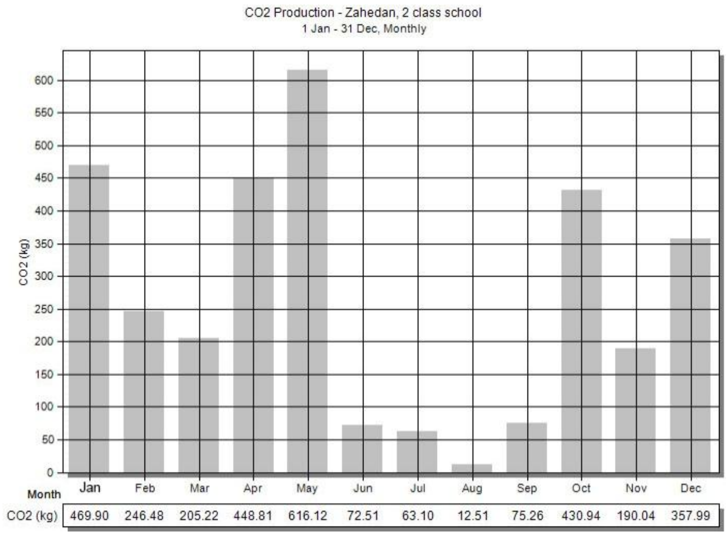
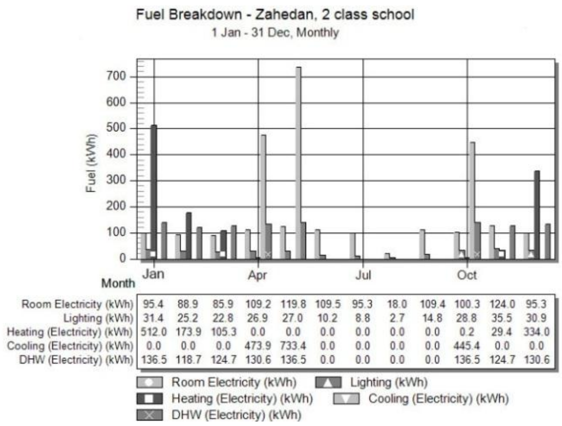



Fig.19. Monthly $CO_2$ Production, Model No.19



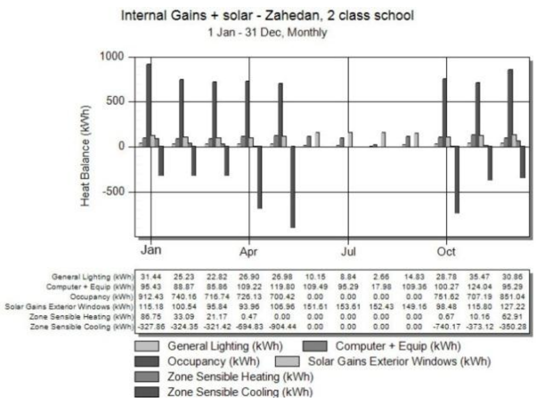




Fig. 20. Monthly Fuel Breakdown, Model No.19

Fig. 21. Monthly Internal gains, Model No.19

Based on the values listed in Appendix, Table (12), the minimum values were calculated, and a 10-degree variance was defined as the minimum energy consumption range. Afterward, to calculate the optimum building orientation more accurately, the mentioned range was re-simulated using models with 1-degree variances and their total annual energy consumption values were compared.

## 5. Results and Discussion

As mentioned, Table (12) presents the annual electricity consumption for lighting and equipment, the energy consumption for cooling and heating, and finally the total annual energy consumption of the 72 simulated models at longitudinal axis angles with a 5-degree Counterclockwise variance.

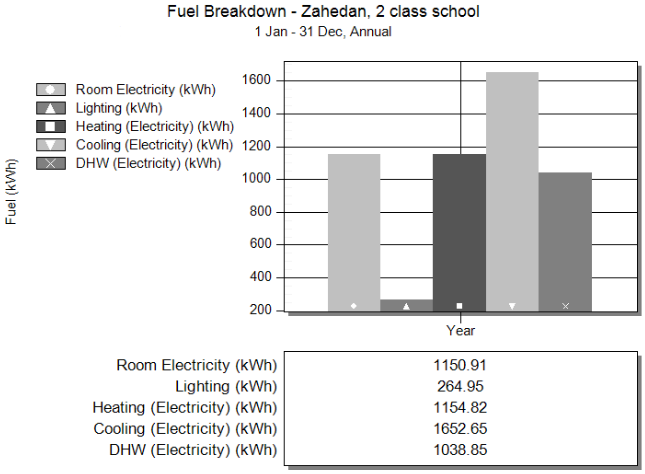



Fig. 22. The annual energy consumption of model No.19, with East-to-west orientation.

It is worth stating that the total annual energy consumption is, in fact, the total energy required annually to provide interior lighting, provide electricity to electrical equipment and appliances, supply annual heating and cooling energy, and provide hot water. These values are shown for model No. 19 at the 90-degree longitudinal axis angle in bar chart No.13.

A comparison of the values listed in Table (12) shows that 5 of the simulated models including models no. 20 to 24, which are linked to the longitudinal axis angles 95 to 115, yield the minimum annual energy consumptions which are lower than 5260 kWh. Figure 22 shows the total annual energy consumption for each one of the 72 models. A close examination of this Chart reveals a periodically descending trend in two ranges.

The mentioned range (from 95 degrees to 115 degrees of the longitudinal axis) is a range that causes minimum energy consumption. Figure 24 show the annual energy consumption values for the 5 models. The analysis of this chart reveals that in the range between longitudinal axis angles 100 and 110, the annual energy consumption is lower than 5254 kWh. Hence, the final model, which yields the minimum annual energy consumption, is represented in this range. To achieve this model, the range between angle 100 and angle 110 was examined using 11 simulated models.

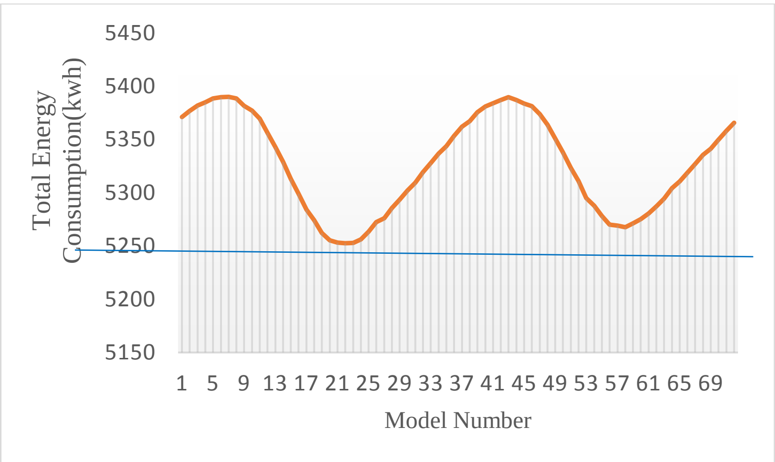



Fig. 23. Total Annual Energy Consumption for all 72 simulation Models.

The longitudinal axis angle in each model is rotated 1 degree clockwise (in the geographic direction). The results from the final 11 models are presented also in Figure 25.

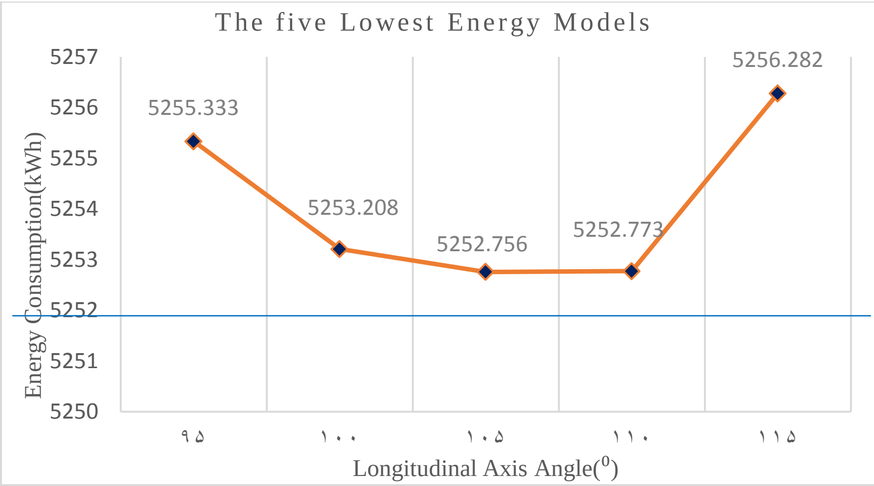



Fig. 24. The area below the red line represents the minimum annual energy consumption

As it can be seen in this Chart, in the range between longitudinal axis angles 100 and 110, the total annual energy consumption of the building periodically changes, and is minimized to 5252.441 kWh at angle 109 degrees.

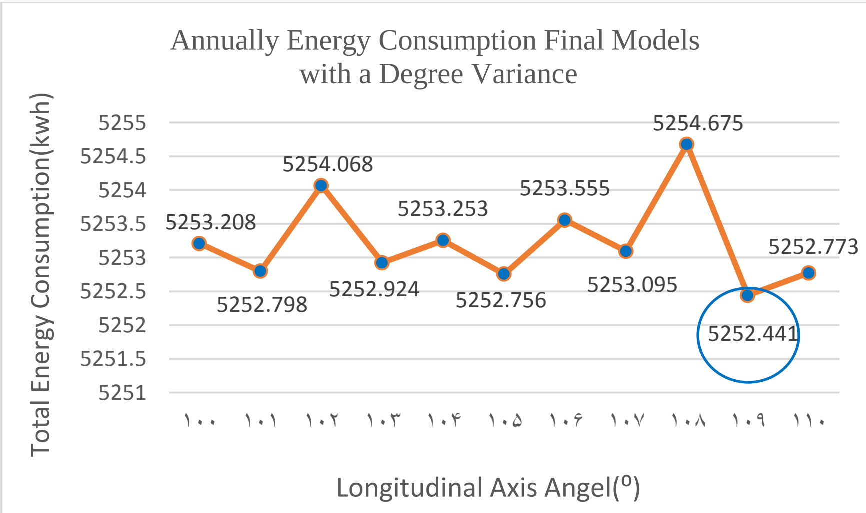



Fig. 25. Annual energy consumptions of the 11 final models with a degree variance
(The circle shows the lowest annual energy consumption which is related to the longitudinal axis angel of 109)

Figure 26 shows the Model with the optimum orientation, which its longitudinal axis has a 109 degree angular difference with the north.

By dint of surveyor cameras, it is possible to construct buildings with a one-degree orientation, but higher accuracy is not achievable due to the construction conditions in villages. Hence, the modeling process was not continued. As noted, the 109-degree orientation yields the minimum annual energy consumption, which is equal to 5252.441 kWh.

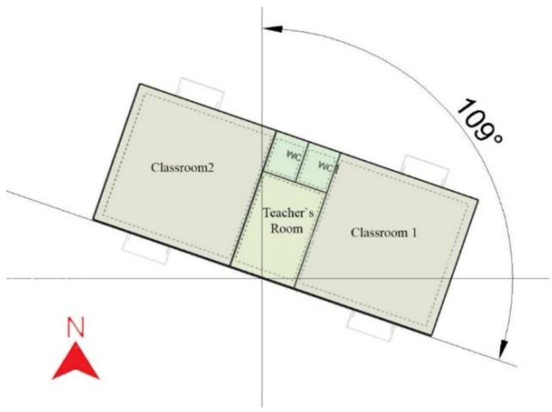



Fig. 26. The final Model with the optimum orientation (109 degrees longitudinal axis)

If this value is divided by the total building area, the minimum annual energy consumption per square meter of this building equals 88.918 kWh/m$^2$. As it can be seen in Table (12) and Figure 23 the annual energy consumption in model no. 7 at the 30-degree longitudinal axis angle is 5390.006 kWh (74.489 kWh/m$^2$), which yields the maximum consumption. The difference between the maximum and minimum consumption rates is also 137.565 kWh. As it was mentioned before, 439 schools have been built based on this plan in the *Sistan and Baluchestan* province. In addition, the life span of school buildings in Iran is about 50 years (mehrnews.com, 2009). Hence, the total energy efficiency in two classroom schools in the province within the life span of school buildings can be calculated by multiplying these three values. This parameter, which is shown by $E_t$, is calculated via the following equation:

$$E_t = n \times 50 \times E_1$$

Where, "n" denotes the number of schools built based on the mentioned plan in the *Sistan and Baluchestan* province and $E_1$ shows the annual energy efficiency for one school. In the total energy efficiency value calculated through the above equation equals 3019551.75 kWh.

Considering that there is no common orientation for building regional schools, the effect (%) of building orientation on the energy saving in the region under study is also calculated via the following equation:

$$100 \times \frac{(The\ maximum\ annual\ energy\ consumption) - (The\ lowest\ annual\ energy\ consumption)}{(The\ lowest\ annual\ energy\ consumption)}$$

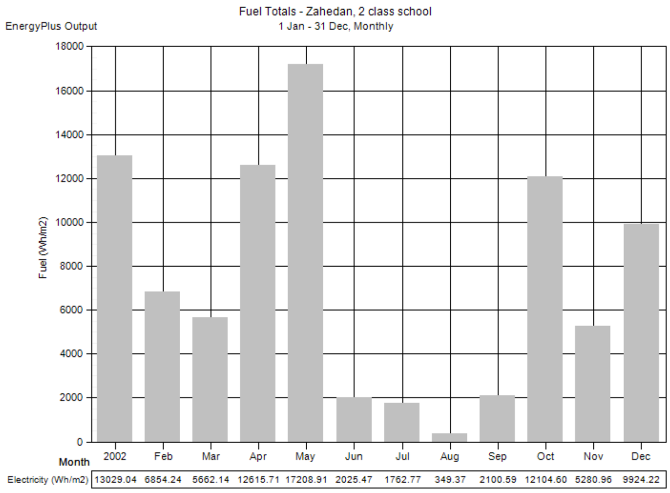



Fig. 27. Monthly energy consumption for the model with optimal orientation (Normalized by occupied floor area)

Solving the above equations using the resulting values unveils the approximately 2.62% effect of building orientation on the energy consumption reduction in the *Zahedan* region. As noted above, however, this amount seems to be low, but due to the large number of typical buildings which are going to be constructed in the province, and their life span, the saved energy amount will be significant.

## 6. Conclusions

In this study, 72 models were separately analyzed through the energy simulation, by which the total annual fuel consumption, total annual energy consumption for heating and cooling, the total electricity consumption of equipment and lighting systems, and the total annual energy consumption were calculated.

As it can be concluded from the Psychometric chart of educational environments in *Zahedan*, in 16% of a year, which is equal to 1401 hours, there is thermal comfort condition in the school, notably in classrooms without any need to use HVAC systems.
The minimum energy consumption is 5252.441 kWh (88.918 kWh/m$^2$), which is obtained in the orientation of the longitudinal axis of 109-degrees.
The maximum energy consumption is 5390.006 kWh (74.489 kWh/m$^2$), which is resulted by the longitudinal axis 30-degree orientation.
The spatial analysis of the schools built in *Zahedan*, reveals that there is not any prevailing orientation for them.
Our data showed that it is possible to achieve a 2.62 % decrease in annual building energy consumption in *Zahedan* by accurately determining the building orientation. Although this amount is negligible, considering the total number of typical buildings in the *Sistan and Baluchestan* province, the energy consumption can be reduced by 3019551.75 kWh, within the 50-year life span of school buildings, reflecting the importance of selecting the right building orientation at the time of construction.
Numerous factors can be analyzed in future research to increase energy efficiency: optimizing material type; using wall insulations, thermal insulations in ceilings, and structural layers in ceilings; adjusting the window to wall ratio, the height of windows from the finished floor (sill-height), the window orientation, the optimum shading length and shading form, classroom depth; and organizing class arrangement when there are more classrooms.

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[ii] All the angles mentioned in this article, are horizontal angles, based on "0" in the north and the clockwise rotation (Compass Directions).
[iii] Heating, Ventilation, and Air Conditioning
[iv] Interview with the head of Zahedan Schools Renovation Organization.
[v] Wladimir Köppen (1846-1940)
[vi] Rudolf Geiger (1954, 1961)
[vii] The solar heat gain coefficient
[viii] polyvinyl chloride
[ix] This is the fraction of heat from lights that goes into the zone as a long-wave radiation.
[x] The fraction of heat from lights that goes into the zone as a short-wave radiation
[xi] Heating/cooling system CoP (Coefficient of performance) is the whole system seasonal coefficient of performance including distribution losses when using the simple HVAC model option.