

Application of Geographical Location Differences of the Sun-Path Diagram in Climatic Architecture

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Abstract

In this study, by recognizing geographical location changes of the sun-path diagram, we present a selection of sustainable architectural guidelines that influence the climatic element of sunshine. For this purpose, after the introduction of triple zones of the earth in terms of how the sun is exposed (include: Tropical, temperate and polar), the function of the earth's curvature to create geographical location differences in the angles of sunshine in both its altitude and azimuth, is explained. In the following, using the "Rayman" software, the sun-path diagram on the days of the summer and winter solstice (revolutionary) is drawn up for cities selected in the triple zones, and the geographical location differences of these diagrams are described. Also, due to the climatic requirement in some of the studied cities, the "PET" index has been calculated, and in the other cities, the "Analemma" graph has been used to determine the frontiers of the sunshine and the number of days per each front. The research findings, suggest a deep geographical location difference in the patterns of the sun-path diagram for the Earth's sunshine zones. At the end, a selection of architectural guidelines for the use of passive solar energy is proposed for residential buildings in the above cities. These guidelines are presented in the following topics: Optimal orientation and determine of an appropriate front for lighting the building and estimating the size of the horizontal overhangs for the sun-facing windows.

Keywords: Sun-path Diagram, Climatic Architecture, Rayman, Analemma, Summer and Winter Solstice.

1. Introduction

With the onset of human ability to build housing, the climate was gradually and at an elementary level. "Even in the so-called primitive architecture, a climate design has been well-documented" (Watson & Lobes, 2011: 3). Over time, human innovations have made the environment more coherent in the components, design and building materials of the houses, and the integration of architecture with the climate, institutionalized. It should be borne in mind that, in today's world, modern technologies only transformed the shape and manner of the arrangements of this integration and could not dampen the principle. Nevertheless, due to the neglect of the principle of environmental coordination, energy challenge and environmental crises have now become apparent as the main consequence of the consolidation and expansion of settlements. "According to the Global Monitoring Institute, buildings account for about 40 percent of global energy production, accounting for about 40 percent of sulfur dioxide and nitrogen oxides" (Arifkamal.M, 2012: 85). "In our country, the largest share of energy consumption belongs to the homemade sector" (Qiyabakloo, 2014: 9). Today, the adjustment of the energy challenge and environmental crises has made it necessary to

apply the approach of nature-alignment to the social and economic life of mankind. In line with the operation of the above approach in housing, the strategy of "sustainability in urbanism and architecture" has been considered. In this strategy, the basic element of the environment is the climatic conditions for homogeneous housing. Obviously, in the study of climate, there are various elements of the atmospheric phenomena that in the present study, the sun's element was studied in the form of a "sun-path diagram". Systematic and scientific study of the function of the climatic element of the sunshine in architecture, the following discussion of comfort temperature that was introduced by people such as: Olgyay (1963), Evans (1980), and Givoni(1984). This study led to the evolution of the topic of "passive solar energy" by people like Kachadourian (2006), who came up with a book with the same title. In this book, the author has attempted to introduce a specific type of passive solar energy based building, and express the function of influential components, such as sunshiny spaces in such a house. Kachadourian has been pursuing heating solutions in cold areas by determining the intensity of radiation and the amount of solar heat in the latitudes of 16 to 64degrees northern and calculating the amount of heat

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needed (degree-day) in cities in the United States and Canada. In the same vein, Bainbridge and Haggard (2011) also pursued a sustainable architecture by means of passive solar energy. The book, with the introduction of various architectural design and sustainable design on one hand, and the selection of structures compatible with the environment (climate), on the other hand, has tried to introduce methods for maximizing the power of the solar power in architecture. In the meantime, and in the course of detailed knowledge of the solar radiation, the study of this climatic element began in the form of the sun-path diagram and by the method of the Sellers (1965). With the advent of IT technology, this process of study by Matzarakis et al. (2007) took a form of software. By designing Rayman software, they created the ability that a climatic architecture researcher could draw the sun-path diagram for all the places on earth for a day or days under study.

In Iran, the sun-path diagram in architectural studies is mainly a controversial discussion in the books and articles in the field of "climate and architecture" and by people such as: Razjooyan (2009), Moradi (2009), Kasmaie (2010), Soflaie (2010), Akhtarkavan and et al. (2011), Ghobadiyan

2. Theoretical Framework of Research

In explaining the concept of the sun-path diagram, it should be noted that the Sun at the time of dawn and west often has an arched path in the sky. "The way the sun passes daily in the sky (in the eyes of the observer), is called:"the path of the sun "(Razjooyan, 2009: 107). The sun always creates two angles of the "azimuth" and "altitude" of the sun at any point in its path in the sky, relative to the observer. "The angle of the sun's altitude is the angle between the observer eye and the sun with the horizon, and the angle of the sun's azimuth is the angle that creates the image of the same radius on the horizon and in the direction of the clockwise with north-geographic direction"(Razjooyan, 2009 :106)Look at (Fig.1).In research on climatic architecture,

and Feyz Mahdavi (2011), Shateriyan (2013), and Qiyabakloo (2014), have been raised. Meanwhile, a special look at the sun-path diagram was made by people such as: Tavoosi (2011). In his book _"Climatic Application of Solar Radiation in Environmental Planning», he described the application and importance of it in climatic design using non-software methods. Also, Mohammadi in the book named "Applied Climatology" (2010) mentions Geographical location differences in climatic architecture policies. By reviewing the studies done, we can say that the plan of Geographical location differences in radiation and the sun-path diagram has not been under a serious attention. Hence, the present article can be regarded as an initial and preliminary effort in this field. Therefore, addressing the differences in the path of the sun along the latitudes and giving a nature of the location to the study of solar radiation, has been the main purpose of this paper and also the presentation of proposed architectural designs, were merely intended to illustrate these differences. Obviously, achieving a pure design without regard to the theoretical and scientific foundations of climatology, is possible easily, by means of special architecture software like:"Ecotect".

including the this research, the daily track of the sun in sky is depicted and used as:" sun- path diagram». To understand how the path of the sun and its Geographical location differences, it is necessary to explain that the curvature of the earth and its motion around the sun, along with the deviation of the axis of this sphere, from the vertical position to the ecliptic or equator of the sun (Fig. 2), provides conditions for the earth's geometry, which forms the condition for the formation of earth's triple zones in sun radiant (Fig. 3). The patterns of the sun- path diagram in the above-mentioned radiation zones is different and is illustrated in Fig. 4 in the first days of the four seasons.

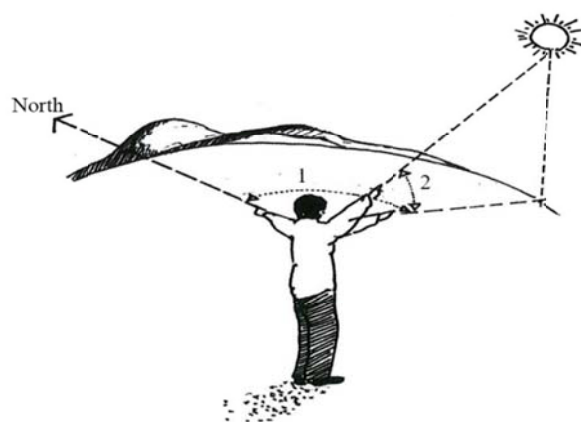


Fig. 1. The sun's azimuth angel (1) The sun's altitude angle (2) (Razjooyan 2009: 107)

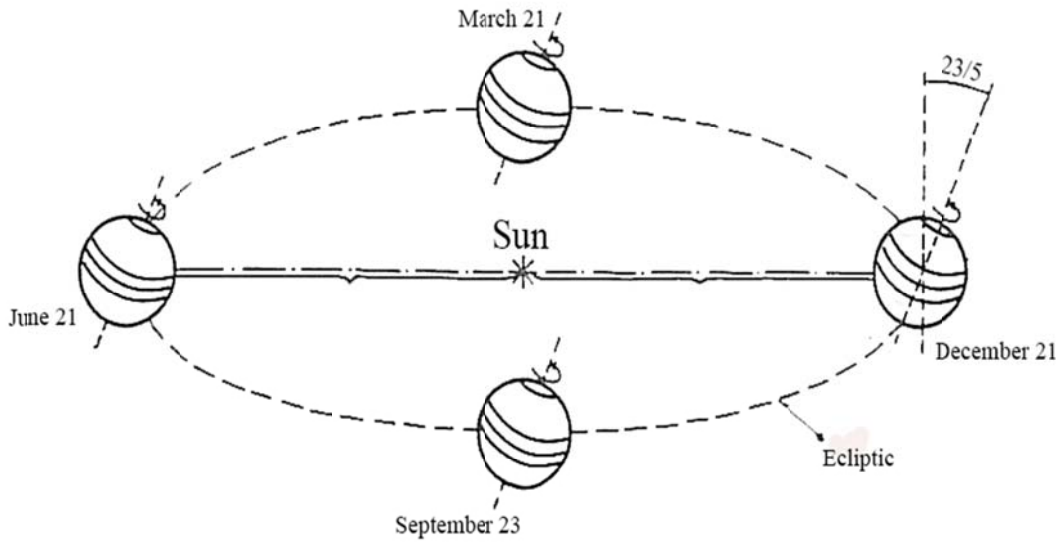


Fig. 2. Earth's geometry on the first day of the four seasons (Alijani and Kaviani, 1993: 58)

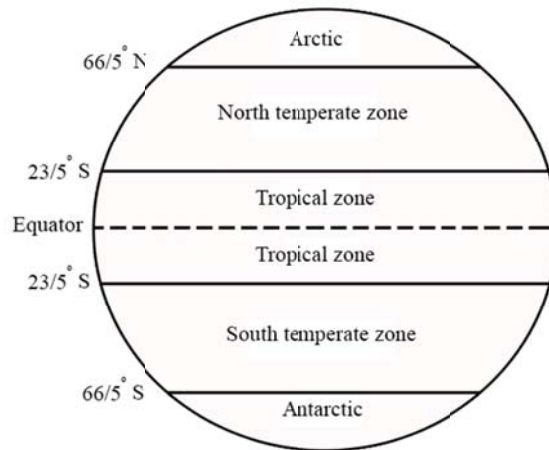


Fig. 3. Radiation zones of the Sun on the Earth

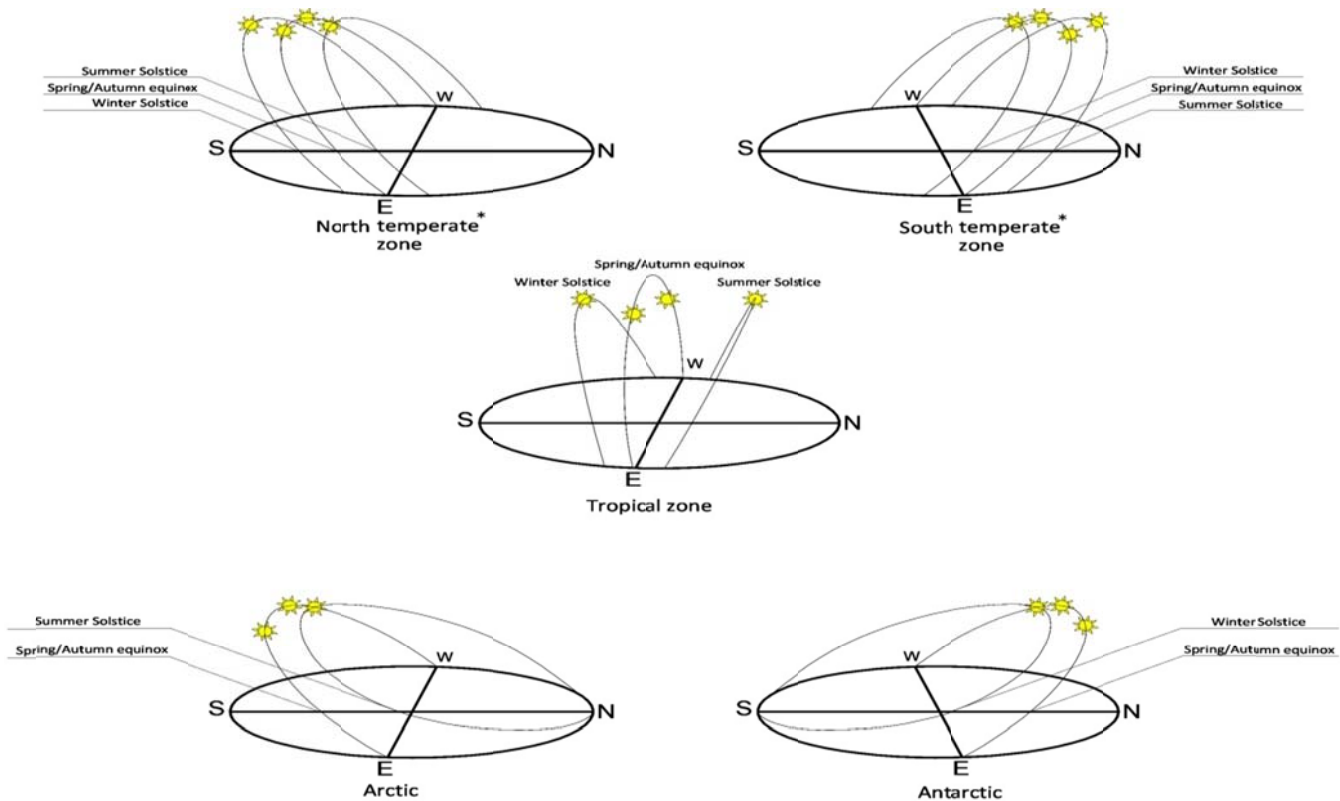


Fig. 4. The sun- path diagrams in first day of the four seasons in the Earth's radiant zones.

According to Fig. 4, a brief introduction of the solar radiation patterns in the earth's triple zones, is as follows:

A- Spring equinox (March 21): On this day, the sun is perpendicular to the orbit of the equator and from east to west, at noon with 90 degrees angle shines on all the equatorial points. In this way, the amount of energy emitted to the two northern and southern hemispheres is equal and the angle of the sun's altitude is identical to the symmetrical orbits in the two northern and southern hemispheres. The movement of the earth around the sun, which takes place on an elliptical path in the direction of the counterclockwise (Fig. 2), ends spring equinox, and from the second day of spring season, moves the earth toward the summer solstice.

B- Summer solstice (June 21): The Earth's moving forward on Earth's annual orbit, causes the axial deviation of the earth to remove the equator from the perpendicular of the perpendicular radiation in two days of the year (once in spring and again in the summer). On the final day of the high trend and in the first day of fall, when the earth takes the position the first day of spring on the position of the annual circulation, for the second time, the solar radiation was recreated in the equator orbit (Fig. 4) and all points on

sun. In this way, the sun displays its perpendicular radiation on the orbits of the north of the equator on the apparent path of its daily movement. The sun's perpendicular to all the northern hemisphere orbits to the Tropic of Cancer (23 degrees and 27 minutes), occurred during the spring, and in the June 21, perpendicular radiation was experienced precisely for the Tropic of cancer and the summer solstice takes place. The sun's moving in the perpendicular radiation until the Tropic of Cancer, is in accordance with the degree of deviation of the Earth's axis from the perpendicular being 23 degrees 27 minutes, and gets an astronomical interpretation.

C- Autumn equinox (September 21): Orbits that had seen the Sun's perpendicularity respectively during the spring, for the second time and during the summer days experience perpendicular radiation. In this way, all the points between the equator and the Tropic of cancer have seen in the sun's the equator at the moment of noon, will see the sun exactly above the head and at 90 degrees angle.

D- Winter solstice (December 21): From the first time of autumn to the beginning of winter the sun's perpendicular radiation is transmitted to the southern hemisphere, and covers all the points between the equator orbit and the

Tropic of Capricorn in the fall quarter. In this way, all the points on the Earth from the equator to the 23 degrees and 27 minutes southern orbit will experience the sun's perpendicularity so that on the first day of the winter the above mentioned state be experienced in the Tropic of Capricorn. It is obvious that for the first day in spring, the sun needs to regain its permeable radiation after six months in the orbit of the equator, so in its apparent motion, the path went in the autumn, will be passed in return in three months of winter, and as to all points in the fall it was once perpendicular, will be vertical for the second time. In this way, during a solar year, all the points between the equator and the orbit of 23 degrees and 27 minutes north and south, see the sun at noon and in two days of the year, in perpendicular. The interval between these two symmetric days from the first day of the first day of the winter and summer seasons is equal.

3- Data and research method

Considering the nature of this research, which is based on Geographical location differences in sun-path diagram, from the triple sunshine zones in the two hemispheres of the earth (Fig. 3), 6 orbits, two by two having the same latitude and symmetry, along with the city and the symbolic place for each of them is selected as follows:

1-Tropical zone (lower latitudes):

- * Northern Hemisphere: Nouakchott city, Mauritania country, latitude 18° Northern.
- * Southern Hemisphere: Harare city, Zimbabwe country, latitude 18° Southern.

2. Temperate zone (middle latitudes):

- * Northern Hemisphere: Ahar city, Iran country, latitude 38° Northern.
- * Southern Hemisphere: Melbourne, Australia country, latitude 38° Southern.

3. Polar Zone (Arctic and Antarctic)

- * Northern Hemisphere (Arctic): Koolan Town, Finland country, Latitude 67° Northern.
- * Southern Hemisphere (Antarctic): Non-residential place in the Palermo Peninsula, latitude 67° Southern.

Numerical data on how the sunshine and sun path in each of the above cities can be considered as materials and data of the study for day's summer solstice and winter solstice. Tables 2 and 3 show these research findings as well. The Rayman software has been used to conduct the present research and draw the sun- path diagram in selected cities. The original version of this software was designed in year 2000 by Matzarakis and his colleagues at the Meteorological Institute of the University of Freiburg. The software has various capabilities in urban, architectural and tourism studies; in this article, the software is featured in the plot of the sun- path diagram, which uses as a more applicable architecture. "Rayman software, in addition to determining the elements of climatic comfort, has the ability to plot sun- path diagram. This software plots the sun-path diagram, according to the latitude of the city studied and the date of the desired date" (Inanlou, 2013: 120). Based on Fig. 5, to do a sun- path diagram of the desired location, should enter the geographic coordinates of the desired location, then enter the path of "output" and after selecting the "Diagram" option, the output is taken as a graph. As shown in Figure 5, the output of the "Diagram" option is available in two Polar modes, with the graph showing the top and the Cylinder (cylindrical), with the graph display facing, in which the Polar option is used. . As an example of the diagram above, Figure 6 shows the sun- path diagram in the city of Qazvin. Of course, in manual drawing, the directional diagrams of the sun can also be displayed from the sides too (Fig. 4).

Determining a number of architectural guides in the earth's temperate radiant zone, requires using bio-climatic index "PET" or "physiological equivalent temperatures" in addition to the sun-path diagram. Among these guidelines, the calculation of the depth of the horizontal overhangs in the windows facing the building sunshine. For this purpose, it is necessary to determine the beginning of the day from the warm period of the year using the PET index. The calculation of the PET index is also done in Rayman's software environment. In the present study, based on the Version 1.2 version of this software, the PET index has been calculated for the cities of Ahar and Melbourne. "The main advantage of this Indicator is based on Celsius and is capable of evaluating on a daily and even hourly basis" (Ismaili et al., 2010: 104). Matzarakis et al. in order to level the different temperature states and determine the extent of their physiological stress, proposed numerical values obtained from the calculation of the PET index in Table 1.

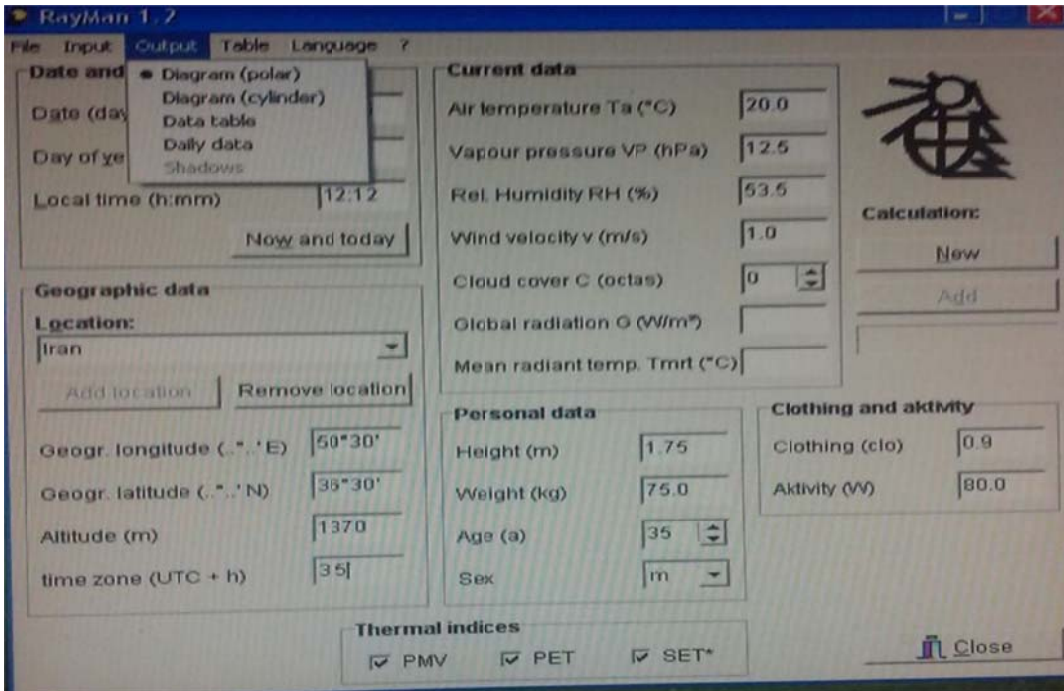


Fig. 5. Getting The sun-path diagram in Rayman Software (Matzarakis A. and et al, 2006)

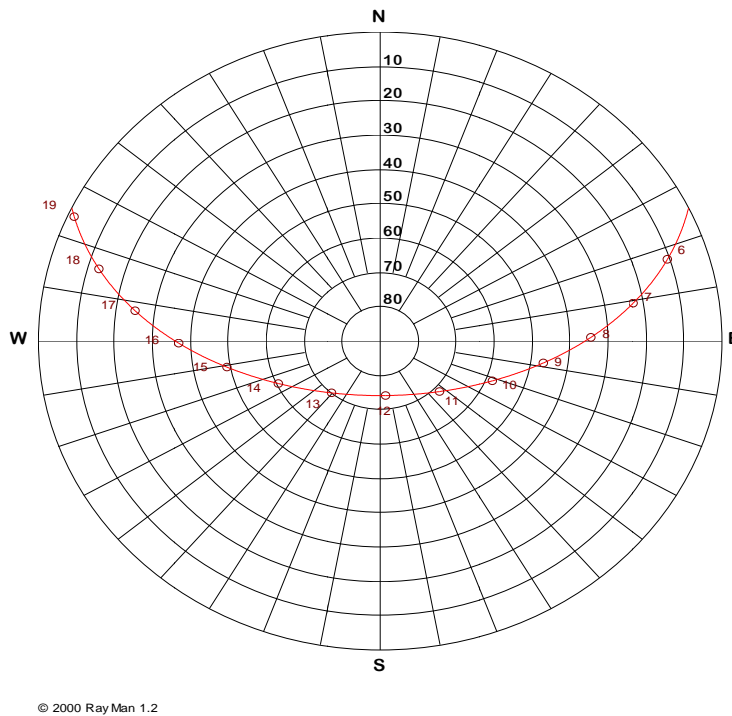


Fig. 6. The Sun- Path Diagram in Qazvin City, on 22/5/2013 (Inanlou, 2013: 121).

Table 1

PET content at different levels of temperature sensitivity and physiological stress (Matzarakis&Amelung 2008: 166)

PET (° C)	Less than 4	4 - 8	8 - 13	13 -18	18 - 23	23 -29	29 - 35	35 - 41	More than 41
Temperature	Very cold	Cold	Cool	Little	Comfort	Little	Warm	to	Hot
sensitivity				Cool		warm		warm	
Physiological	very intense	intense	Medium	Little	without	Little	Moderate	Intense	Heat is very
stress size	cold	cold	cold	cold	stress	heat	heat	heat	intense

Given the specific sunshine patterns in the tropical zone (Figure 4), the use of the sun-path diagram to reach the climatic architectural guidelines in this zone, requires the determination of the below days for under study cities (Nouakchott and Harare). To do this, the "analemma" graph is used.

- * Determining the two days of the year when the sun's perpendicular is visible;
- * Determine the number of days of the year when the direction of sunshine and the apparent motion of the sun is from the south front.

* Determine the number of days of the year when the direction of sunshine and the apparent motion of the sun is experienced on the northern front.

The diagram of "Analemma"(Figure 7) is an indication of the orbit that the sun percolates perpendicularly. In this way, in addition to determining the days of the sun's inclination for perpendicularly to the orbits in the tropical zone, it also shows the days of the sun on the southern and northern front of each of the orbits of in this zone.

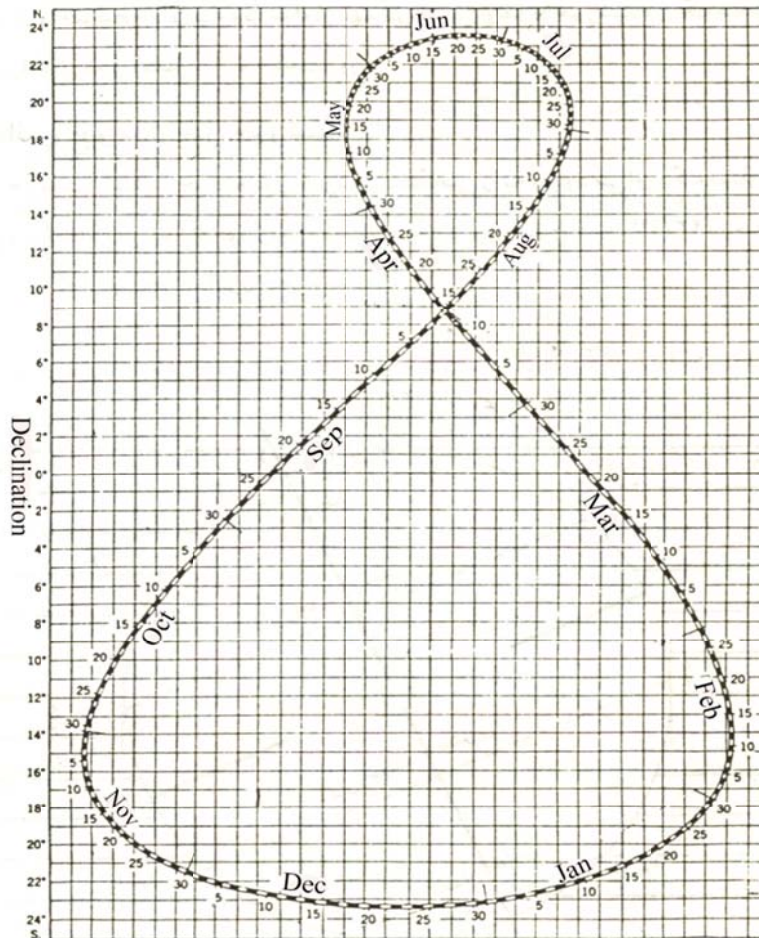


Fig. 7. The diagram of Analemma (Alijani and Kaviani, 1992: 60)

Table 2
Geographical location differences in the sun-path diagram for the cities studied on the summer solstice

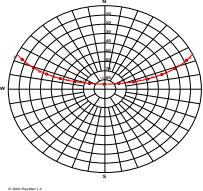
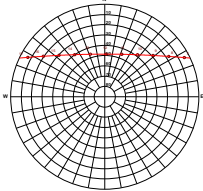
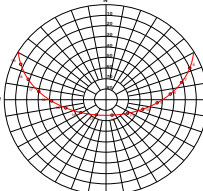
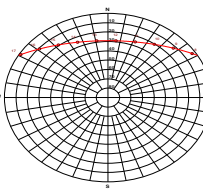
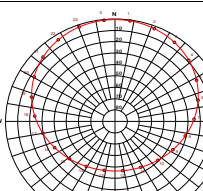
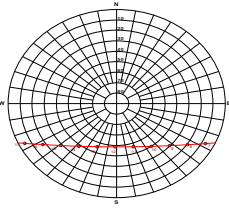
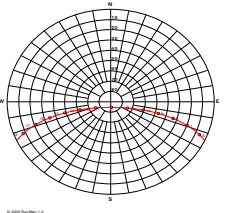
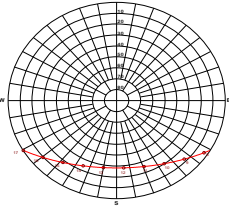
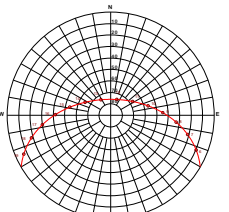
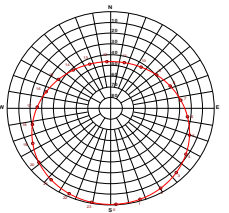
Statistical data obtained from the sun- path diagram						City Name
The sun's altitude at noon moment	Front of the sun's motion in the sky	Daytime (hour)	Sunset side	Sunrise side	Sun- path diagram	
84 Degrees	North	13 . 15	West of the northwestern	East of the northeastern		Nouakchott (18 degrees) Northern
49 Degrees	North	10 . 55	West of the northwestern	East of the northeastern		Harare (18 degrees) Southern
75 Degrees	South	14 . 41	West of the northwestern	East of the northeastern		Ahar (38 degrees) Northern
30 Degrees	North	9 . 25	West of the northwestern	East of the northeastern		Melbourne (38 degrees) Southern
47 Degrees	The sun does not have a sunset and it's all 24 hours in the sky. Its path is circular in the sky and begins from the north and ends in the north after 24 hours. So the sun spins 360 degrees on a 24-hour day. The movement of the sun toward the horizon is wavy and at peak times at noon and finds the smallest altitude at 24 o'clock.					koolan (67degrees) Northern
Without the sun's diagram, it's all 24 hours a night. Therefore, the sun does not appear in the sky, and the direction of the sun's movement in the sky and its elevation angle can not be determined.						Palmer (67 degrees) Southern

Table 3
Geographical location differences in the sun-path diagram for the cities studied on the winter solstice.

Statistical data obtained from the sun- path diagram						
The sun's altitude at noon moment	Front of the sun's motion in the sky	Daytime (hour)	Sunset Side	Sunrise side	The sun path	City Name
49 Degrees	South	11	West of the southwest	East of the southeast		Nouakchott (18 degrees) Northern
84 Degrees	South	13 .10	West of the southwest	East of the southeast		Harare (18 degrees) Southern
30 Degrees	South	9 . 20	West of the southwest	East of the southeast		Ahar (38 degrees) Northern
75 Degrees	North	14 .35	West of the southwest	East of thr southeast		Melbourne (38 degrees) Southern
Without the sun's diagram, it's all 24 hours a night. Therefore, the sun does not appear in the sky, and the direction of the sun's movement in the sky and its elevation angle cannot be determined.						koolan (67 degrees) Northern
47 Degrees	The sun does not have a sunset and it's all 24 hours in the sky. Its path is circular in the sky and starts from the south and ends in the south after 24 hours. So the sun spins 360 degrees on a 24-hour day. The movement of the sun toward the horizon is wavy and at peak times at noon and finds the smallest altitude at 24 o'clock.					Palmer (67 degrees) Southern

4. Research Findings

As research findings, it should be noted that the execution of the sun- path diagrams for the studied cities and the extraction of numerical data related to these diagrams in the summer and winter solstice days are presented in Tables 2 and 3. Although it is possible to generalize the findings on the angles of the sun for each city to all the locations on the orbit of that city, but these tables indicate the sharp differences between the radiant areas that have been implemented with the symbolic study of the above cities. The completion of the study objectives required this study in addition to the sun-path diagrams in the tables above, the results of using the "PET" index and the diagram of the "analemma" should be considered. These findings are presented in the continuation of the article and after tables 2 and 3.

Although the findings of Tables 2 and 3 are sufficient to reach the suggestions for polar cities, this is inevitable for the temperate zone, the implementation of the PET index, and the "Analemma" graph for the tropical zone. The findings from the implementation of the above indicator (index) and graph are as follows:

* **PET Index:** The implementation of this indicator for the two cities of Ahar and Melbourne showed that the first day of the warm period of the year, which caused a lack of Thermal comfort, for the city of Ahar on May 6th at a shine angle of 68 degrees and for the city of Melbourne on the seventeenth day October with a shine angle of 61 degrees. Obviously, the radiating angles of these days are the basis for calculating the depth of the horizontal overhangs for sun-facing windows of the buildings (Fig. 9).

* **Analemma Graph:** Based on Fig. 4, the main characteristic of the sun- path diagram in the cities of the tropical zone is that the sun, despite its perpendicularity in two days of the year, in some days of the year from the south front and in other days of the year from the northern front to them shines. In order to determine each of the above days, along with the corresponding radiation angle in the cities studied by the Nouakchott and Harare, the "Analemma" graph shows the results of Table.4.

Table 4
Direction and altitude of sunshine in the cities of Harare and Nouakchott based on the " Analemma" graph

The smallest angle of shine on the northern front	The smallest angle of shine on the southern front	The period of shine from the northern front	The period of shine from the southern front	Days of perpendicular sunshine	City Name
84.5 degrees on the June 21	48.5 degrees on the December 21	From May 15 to July 28	From July 30 to May 13	May 14 and July 29	Nouakchott
48.5 degrees on the June 21	84.5 degrees on the December 21	From January 28 to November 14	November 16 to January 26	November 15 and January 27	Harare

It should be noted that the cities of Nouakchott and Harare have no cold season, and heat is prevailed throughout the year. Therefore, in the climatic architecture of these cities, it is imperative to avoid sunshine exposure to the building for the whole year. Hence, the smallest amount of angles radiations of the sun in the days of the northern and southern front was the basis for calculating the size of the horizontal overhangs for sun- facing windows in the buildings of these cities (Fig. 10)

5.Conclusion and suggestions

As shown in Tables 2 and 3, the sun-path diagram in each geographic location, its various climatic elements, such as: the time and direction of sunrise and sunset, the length of the day, the angle of altitude and the sun's azimuth at different times of the day is showing. Each of the above, along with the findings of the "PET" index and «Analemma" graph can guide the design and

implementation of climatic architecture guidelines and guide the building designer in this direction. In this regard, as research suggestions, architectural guidelines can be consider from the sun-path diagrams in the topics of: optimal orientation of the building, the determination of an appropriate front for illumination, locate and calculation of the size of the window overhangs of the buildings in the studied cities of the triple zones of the earth, presented.

A) Polar region (Palmer and koolan) :In the orbit of the 67degrees north and south, the sun, with the exception of a few days from the year that does not rise; in the rest of the days, runs the arc to the full circle in the sky. Hence, all the fronts of the building (with the maximum in the south front for koolan and the north front for Palmer) are capable of receiving light and sunshine. Therefore, located the building skylights on all fronts with Emphasis south of koolan and

north for Palmer is proposed. In such a way, the architect builds an "arched shape" design in the polar region. Obviously, in terms of the direction of the building, the axis of such a building should be aligned with the meridian of the desired location, and the body of the Trigger of the building in koolan is in the south and in the "north side" in Palmer. In the case of the horizontal overhangs of windows and skylights, it should be noted that the climatic conditions governing polar zones do not require the use of overhangs. Because always and for all days of the year, because of the lack of (thermal comfort due to the) heat dissipation, polar buildings need to receive solar radiation. Figure 8 shows the design of the above cases with a simple graphic for the tower of koolan and the Palmer peninsula.

B- Moderate (Ahar and Melbourne): The climatic conditions of the Earth in the temperate zone are of the highest complexity and with the function that affects humankind, it also diversifies all aspects of human life, including architecture and housing construction. Hence, the implementation of sustainable architecture in the temperate zones of the Earth, especially in its northern hemisphere, has the highest density of urban settlements, is faced with many complexities and delicacies. Therefore, it is necessary to conclude this study separately for the cities of Ahar and Melbourne.

* **Ahar city:** Considering that the proper front for lighting of the buildings in Ahar is the southern front, hence, the rectangular shape of the building is desired and suggested. It is necessary to direct the rectangular shape from the west to the east with the overlap of the north-south axis of the building on the meridian of the construction site. In this city, the existence of a warm year period will inevitably cause the design of the horizontal overhangs for the windows to the south. The size of this overhangs is given in

Fig. 9, with respect to the beginning of the warm period of the year in Ahar, as discussed above.

* **City of Melbourne:** Due to the location of this city in the southern hemisphere, the front is suitable for lighting buildings to the city of Ahar (which is) on the northern side. However, the fact that Melbourne is in the southern hemisphere is not a change in the shape of the building, and a rectangular shape of the building is also proposed for the city. It is also necessary to consider the direction of the rectangular shape from the west to the east and with the alignment of the north-south axis of the building on the meridian of the construction site. In the city, the existence of a warm period of the year also makes it imperative to design a horizontal overhangs for sun-facing windows (north). Depending on the beginning of the warmth of the year in Melbourne, as previously defined, the depth of the horizontal shadow can be taken as Figure 9. This figure shows the design of the case for the two cities of Amar and Melbourne with a simplified drawing.

C-Tropical zone (Harare and Nouakchott): As the research findings show, the location of the cities of Harare and Nouakchott in the tropical region reveals a pattern different from the cities of temperate and polar zone in terms of how the sun-path diagram for these two cities is showing and requires specific climatic architectural guidelines. Therefore, it is necessary to consider the located of windows and skylights' position on both the northern and southern sides of the building. Of course, the hot and humid weather conditions governing the tropical region make the designing of horizontal overhangs for the windows and skylights of both fronts, a vital case. Obviously, the size of these shadows will be symmetrical in the two cities of Nouakchott and Harare. Figure 10 shows the size and design of the overhangs in the above cities.

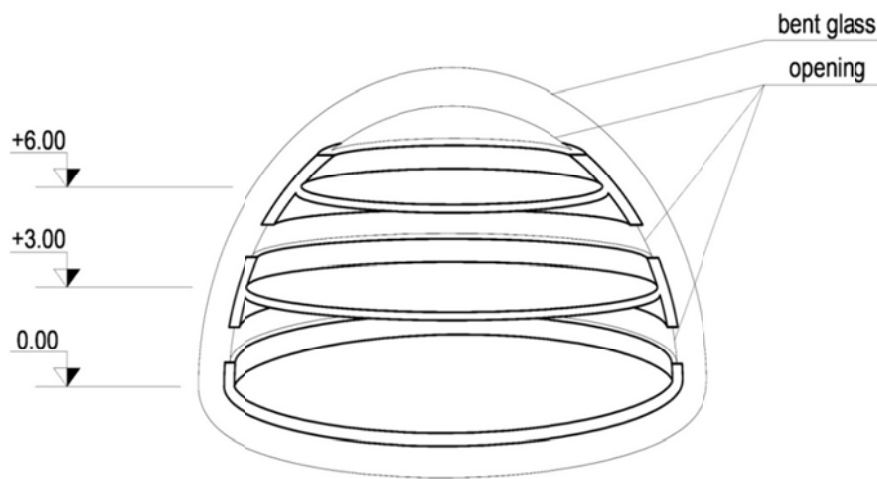


Fig. 8. A simple design of climatic architecture corresponding to the sun path diagram in koolan and palmer

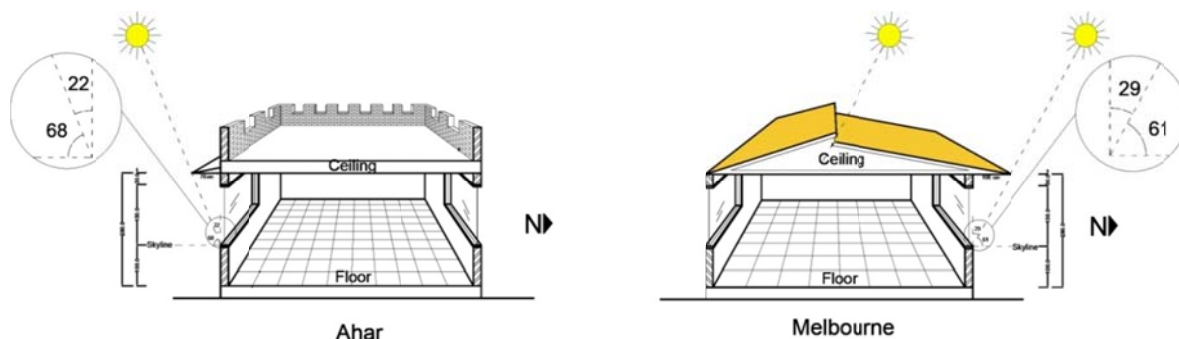


Fig. 9. A simple design of climatic architecture corresponding to the Sun path diagram in Ahar and Melbourne

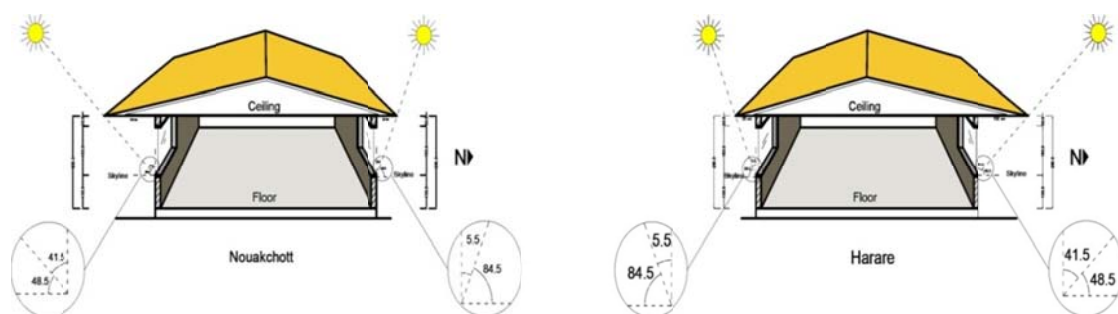


Fig. 10. A simple design of climatic architecture corresponding to the Sun- path diagram in Harare and Nouakchott

Endnotes

¹Temperate zone: An zone that located between the latitudes of 23.5 and 66.5 degrees in both north and south hemispheres (Mohammadi, 2007: 163)

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