wjert, 2018, Vol. 4, Issue 1, 118-138. Original Article ISSN 2454-695X

World Journal of Engineering Research and Technology
WJERT
www.wjert.org SJIF Impact Factor: 4.326

SOLAR BASED STREET AND BUILDING ORIENTATION THE CASE OF SNNPR CITIES LATITUDE 6^0 AND 7^{0}N

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Article Received on 13/11/2017 Article Revised on 04/12/2017 Article Accepted on 25/12/2017

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ABSTRACT

Urban design involves working with different professionals and different complimentary skills. The issues are broad; social, political, planning, engineering and geographical. The climate respect should be viewed in this perspective. The current globalization pressure is exerting a force which is powerful enough to pulling the construction and designing of dwellings in a standard manner discarding all efforts of the all. It is critical time localizing our effort to this magnitude of direction. This approach is clearly leading to loss indigenous sun orientation and urban design interface of solar based street and building orientation which give the suitable thermal comfort of the dwellers. The history of urban development and designing a city is a recent era in Ethiopia. This study focused the study area streets and buildings are designed considering of topographic situation rather than sun orientation. The prolonged exposure to solar radiation or UV resulted a serious health problem in respective cities. Some methods, procedures, measuring techniques and different software demonstrations are used to conduct the result. Identification of existing street, positioning the sun in the sky for selected city and sketching the shadow length for critical time for seven months are steps followed in this research. Finally the researcher ensured NNE-SSW and NNW-SSE street orientation and E and W facing buildings orientations are the best, whereas E-W, NWW-SEE and NEE-SWW oriented street and S-N and NW-SE oriented buildings are highly exposed to sun. The researcher derived a linear equation of shadow length for critical times for these months of longest, equal and shortest day lengths and proved comfort street width for seven months, SW=SL*H.

KEYWORDS: Orientation, comfort, shadow length.

INTRODUCTION

As more than a quarter of the urban areas are usually covered by streets, designing urban streets plays an important role in creating the urban climate. The urban streets vary in geometry as defined by height/width ratio (H/W) and length/width (L/W) and also the orientation that is defined by its long axis. These parameters directly influence the absorption and emission of solar radiation and also urban ventilation which have a significant impact on the temperature variations within the street as well as the surrounding environment (Shashua-Bara & Hoffman, 2003).

According to (WHO, 2006) and (Givoni, 1997) sun is a central point for all living things on the earth. It has both useful and harmful effects especially for life near to equator. The beneficiary impact of sun are warmth, photosynthesis, vitamin D synthesis, kills pathogens, phototherapy and light, whereas the harmful effects are sun burn, premature ageing, immune system damage, skin cancer, photosensitivity and eye damage. Exposure to sunlight enables the body to produce vitamin D, which plays a crucial role in skeletal development, immune function, and blood cell formation. According to (Lanks, 2014) bad sunlight management will waste energy and bring health problems and according to (WHO, 2006), prolonged exposure to UV radiation can cause serious health damage especially in tropical region. Furthermore, sun exposure can cause skin cancer and ageing, suntan, sunburn, malignant melanoma, eye inflammation/cataract and weaken the immune system. Traditional architecture in hot climate countries indicates a preference of the east over the west for summer. This fact was mentioned also by (Olgyay, 1963), (Miller, 1980), (Clark, 1980).

According to (Shishegar, 2013), the importance of orientation in a building must be considered at the outset, when the architect is planning the location of the building on the site, the aim being to ensure the maximum availability of useful natural light and sunlight to the interior. Sunlight in a new development can be considerably improved if the buildings are designed to overshadow (for hot climate zone). But in a polar and temperate region the sun light is rare over shading is not recommended.

In Ethiopia, according to BLH cancer department, diseases like skin cancer, melanoma and kaposis sarcoma are common diseases caused by solar radiation. BLH, from 2000-2004 E.C. numbers of patients with these diseases (skin cancer, melanoma and kaposis sarcoma) are1150 or it is about 0.58% of total patients in cancer department and according to HRH 8.5% of total patient annual being affected with skin cancer, melanoma and kaposis sarcoma.

It is important in tropical and sub-tropical regions more than anywhere else in the world, careful and detail consideration of analysis before initial design phase has to be made. Micro-climatic data collection for future building site needs to become an indispensable part of any design projects in tropical climates in order to achieve sustainable designs with reduced demands on mechanical system, energy consumption and to avoid adversely affecting physiological and thermal comfort. It is applicable that all street layout, building facades, and their orientation envelope response to solar radiation (Markus, 1980). Looking some examples from world, Cairo in Egypt, north to south circulation axis provides the desired ventilation and Ahmedabad in India, main street layouts are oriented on an east-west axis and minimum shading is provided by the use of predominantly row-houses arranged along narrow alley ways.

City streets are functioning like blood system of human anatomy. They are important things to control urban climate and thermal comfort of a city if they designed and oriented well. Traditional and contemporary architectures make a lot efforts to design urban streets according to climate, quantitative information about the best possible street design, based on scientific methods, in order to regulate the climate comfort is still required (Asimakopoulos, et al., 2001).

According (Littlefair, 2000) narrow streets and courtyards provide extra shade as they stop the access of direct solar radiation at ground level for most of the day, especially in orientations NE–SW or NW–SE. And wider streets can become efficient in terms of summertime thermal comfort if they include awnings or other shading devices which protect the occupied spaces from solar radiation. An advantage of wide streets from the thermal point of view is that they can include streetscape elements (such as street furniture, seating, vegetation, trees, shelters, canopies, structures and water features) to promote shading and good comfort conditions.

Based on (SCPG, 2007), a pedestrian focus in planning is important as most people who do not own vehicles and other transport options are costly. So the reason, the concept of sustainable community units emphasis the need to provide the requirements for daily life within walking distance of households. Safety from a technical as well as solar radiation perspective is an important aspect of the pedestrian focus as people need to feel safe while using the pedestrian network and it should be able to be used at all times of the day and night. Pedestrian walkways are not only provided as a courtyard or glass roof covered but also with trees in the open sky. A good pedestrian walkway is designed with well oriented trees on sidewalks.

Plants are used in high ways or medians and edges especially on curves to help reduce the glare of oncoming light. So identifying types of tree planting on the street and understanding their shading distance is important for a city designer. Trees are a premier sun light absorber next to buildings and they shade sidewalks properly when planted well. Deciduous tree species are important type for many landscape architects to design a street landscape for human comfort. They obstruct solar radiation or filter or reduce the reflection (Dines & Kyle, 2001).

In hot climates, an area is more pleasant to walk through, if it is well planted with urban landscape trees. Deciduous trees can be particularly useful in areas with strong seasonal differences. The leaves create shade in the summer when the most radiation strikes the ground and the leafless trees let the warmth through in winter (Beer & Catherine , 2000). According to (Littlefair, 2000), solar shading is valuable for reducing the heat entering buildings and therefore improving comfort and reducing cooling costs.

As (Abebe, 1968), the major elements of climatic environment which affect human comfort can be summarized as sun radiation, temperature, air movement and humidity. These factors act on the human body and can affect the efforts of man both physically and psychologically.

Except this document, no further study is conducted in Ethiopian cities about sun path, street and building orientation relationship. However, the government of Ethiopia is urging city development by making more efficient use of urban land. A great deal of attention has been placed on an ideal opportunity to develop a sustainable community with mixed use of urban land. Most of the planners and designers are initiated to design a city with its social, economic, cultural and aesthetic values depending on the topographic and other parameters of the area. But the consideration of the geometry and orientation of sun is poor because Ethiopian cities have no measured and tangible sun path orientation.

So, the investigation initiated solar based street and building orientation in selected latitude cities to create sun direction manual for new developments and to recommend remedial measures for the existing street layout and building orientation with respective sun paths.

Problem statement

With the fast rate of urbanization in Ethiopia, cities are growing both vertically and horizontally. Man is string for good environment to inhale fresh air and attain natural ventilation in his indoor and outdoor space.

Giving a carful view for our cities, they are both planned and unplanned. Although they are planned with good street layouts, paved with good materials; jangled buildings of soaring height, etc., the consideration of solar orientation for human comfort is minimal.

As sun is a central unit of living organisms, prolonged exposure to UV radiation can cause serious health damages like skin cancer, sunburn, suntan, skin aging, eye cataract and enhance weakened immune system on such apathy designed cities. Since Ethiopia is a country in tropics, she is also the first class of such problematic zone receiving maximum sun light per a year. Not only these, from my daily experience, walking in winter at noon is impossible without being umbrella. Choosing taxi or Bajaj is desirable rather than walking on foot, wearing a single body-shirt is best known for hot seasons to balance the body temperature. Shops facing to Main Street are using plastic cover overhung to shade the front or to reflect the sun rays. The city dwellers are using all mentioned methods to minimize daily hotness and to cool their interior. At noon, sitting under a tree is the usual process of the people the room temperature is higher than that of outside. These necessitate thinking about street and building orientation. Building facades; window openings; pedestrian walkways and street plantations design are not dictated by the path of the sun and its effect upon the health of inhabitants of the respective cities. From these symptoms of the problem, this research strives to answer the following question.

GENERAL OBJECTIVES

To develop solar based street and building orientation for SNNPR cities.

Specific Objectives

1. To find the best street and building orientation for selected cities of SNNPR based on the respective sun path, for human comfort.

2. To identify the effectiveness of existing streets and building orientation against the actual sun path.
3. To develop new guideline of sun path for the street and building design principles based on theoretical and actual solar system with scientific evidence.

METHODOLOGY

Descriptions of study area

SNNPR is located in the Southern and South-Western part of Ethiopia. Astronomically, it roughly lies between $4^0.43 – 8^0.58$ North latitude and $34^0.88$- $39^0.14$ East longitude. It is bordered with Kenya in South, Sudan in South West, Gambella region in North West and surrounded by Oromiya region in the North West, North and East. Profile of selected cities of this research, Awassa, Hossaina, Sodo and Tepi is summarized below in Table 1.

Table 1: Selected cities locations.

City	Astronomic location	Elevation (m)	Population (2007)	Climate	Street Layout
Awassa (capital)	7°3′N 38°28′E	1708	259,803	Moderate Sub-tropical highland	Grid
Sodo (zonal)	6°54′N 37°45′E	1600-2100	163,771	Moderate Sub-tropical highland	Modified grid and unplanned
Hossaina (zonal)	7°33′N 37°51′E	2177	69,957	Moderate Sub-tropical highland	Modified grid
Tepi (Zonal)	7°12′N 35°27′E	1,097	34,491	Highland	Radial and modified grid

Sample

Of all cities found in SNNPR, based on population size and latitude, Awassa, Hossaina, Sodo and Tepi are selected to derive conclusion for given latitudes.

Procedures

Step 1: Sorting of existing street and building orientation and measure and group width of street in to the eight cardinal directions.

Step 2: Designing/sketching the sun path diagram using Aut-CAD and Ecotect 2011.

Step 3: Calculating shadow length for each time interval of the day from 4:00 – 10:00 o'clock local time for 22nddays of months, June, May, April, March, February, January and December.

Step 4: Identifying different altitudes same time for different months and determining critical time gap for shade needed.

Tools

- Arc GIS for identification of street orientation, width and length.
- Auto-CAD for sketching the sun path diagram and determining shadow length.
- Ecotect 2011 for cross check of sun path diagram drawn by Aut-CAD and determining altitude.
- Sketch up to check shadow length in 3D.
- Sun time for determining sunrise, sunset and solar noon.
- Excel for calculation of declination, azimuths, altitudes etc.

Methods

1. Projecting the sun path using stereograph. The path of the sun can determined for each degree of the respective cities latitude for 22nd day of seven months; June, May, April, March, February, January and December.
2. Determination of hour on the stereograph from sunrise to sunset.
3. Graphical construction of shadow for selected time interval (4:00-10:00) local time of seven months for eight cardinal direction of street and sixteen building orientations. Steps are as follows:

Step 1: Laying eight street orientations with constant street width.

Step 2: Putting a building parallel to the street on both sides without setbacks.

Step 3: Move the sun ray or azimuth from stereograph direct to the one corner of the building.

Step 4: Determine the building height and draw its height perpendicular to next parallel ray.

Step 5: Draw a line from the end point of height to the azimuth angle of altitude. Figure 1illustrates the steps discussed (Neufert, 1936).

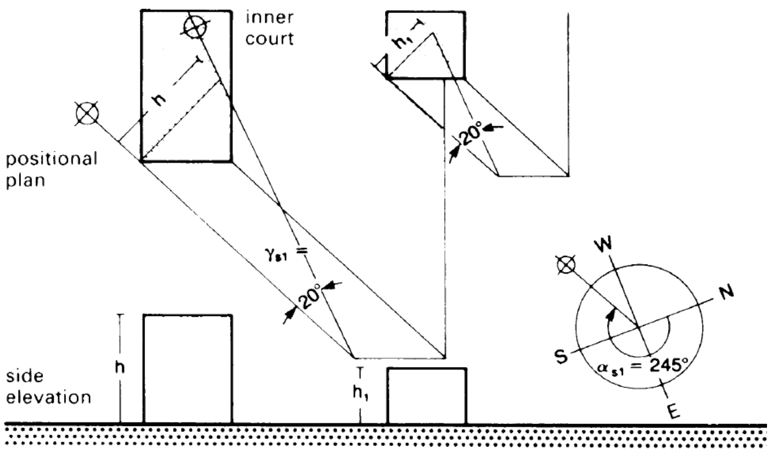


Figure 1: Shadow projection method from stereograph.

From Figure 1 the length of shadow is determined by the vertical edges of the building, that is, a rotation of a true height of the building (h) and application of the elevation/altitude angle of 20^0. The point intersection with the direction of the shadow gives the length of the shadow.

Measurement

Drawing the sun path diagram of the respective latitude of cities is the measurement for checking the existing street and building orientation (Neufert, 1936). To do this, it is important to know the latitude of the city given, azimuth, altitude, and declination of the sun. The orientation of street and building for the different hours and seven months of a year, June, May, April, March, February, January and December are corrected to the orientation of the sun.

Important calculations used

Declination (D)

$$\boldsymbol{Declination} = 23.5\, x\ sin\{\frac{360}{365}(284+N)\}\boldsymbol{Degrees}\ (1)$$

Where N is the day number of the date for which the declination is being calculated. It starts from January 1^{st} as day number 1 and goes up to December 31 as day number 365.

Positioning the sun in the sky

The position of the sun in the sky is described by two angles that are shown in Figure 2.

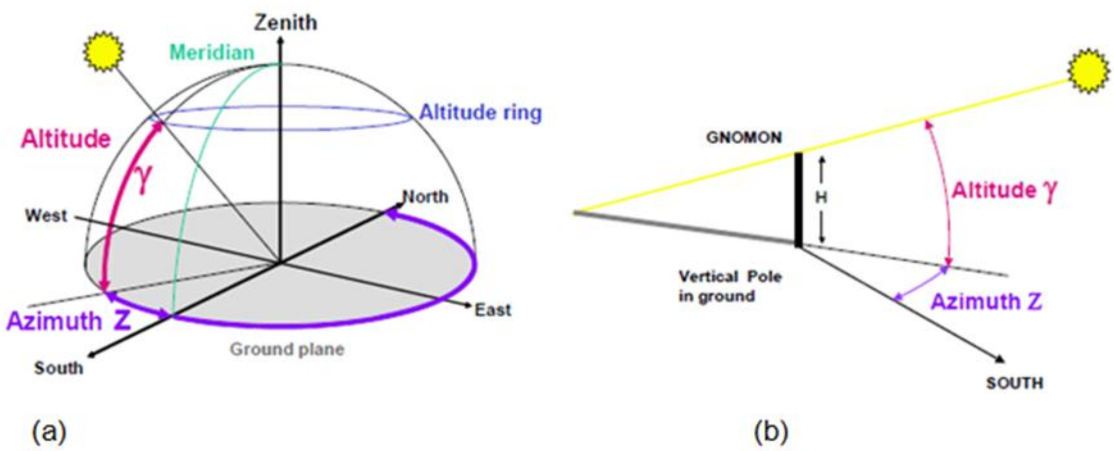


Figure 2: Hemisphere of sky and shadow of the pole (a) & (b).

(Source: www.google.com/Predicting the sun position)

$$LS = \frac{H}{\tan\gamma}\ (2)$$

Where LS is length of shadow, H is hour angle; ϒ is the Altitude of the sun above the ground (horizon) plane and the Azimuth, which is the compass direction of the sun on the ground plane.

$$sin(Al) = sin(\theta)\, sin(\beta) + cos(\theta)\, cos(\beta)\, cos\,(h) \qquad (3)$$

$$Cos(Az) = Cos(\beta)\, sin(\theta) - cos(\theta)\, Sin(\beta)\, cos\,(h)/Cos(Al) \qquad (4)$$

For the summer solstice, June 21st, when the declination is $+23{\cdot}4^0$, solar noon (ϒ) is calculated by Equations.

$$\Upsilon = 90 - L + D \quad (3)$$

Where for the azimuth of sunrise and sun set equation is given as:

$$CosZ = \frac{-SinD}{CosL} \; (4)$$

Where, Z is azimuth angle angle/sunrise or sunset at ϒ=0, i.e. $cosz_{\Upsilon=0} = -sinD/cosL$

$$HA = ST\ x\ 15 + 180° \quad HA = (\, h - 12)15° \; (5)$$

Where HA is hour angle, ST is solar time in hour from midnight and h is hour in solar time So the equation of the time is written as equation 8.

$$\mathrm{ET} = \mathrm{ST} - \mathrm{T} \;\; (6)$$

Where, ET is equation of time and T is time by hour

Since sun travels 360^o in 24 hours or 15^o per 1 hour, the difference between local time and country standard time (d) is given by equation 9.

$$d = \frac{P-R}{15} + ET \; (7)$$

Where, P is point from longitude and R is reference meridian for a country

RESULT AND DISCUSSION

Results

Sunshine of Awassa

Monthly average sunshine hour of Awassa 2005 G.C

Table 2: Monthly average sunshine hour data of Awassa.

Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
9.8	9.1	9.0	6.8	7.5	7.0	5.8	5.7	6.4	7.6	9.2	9.4

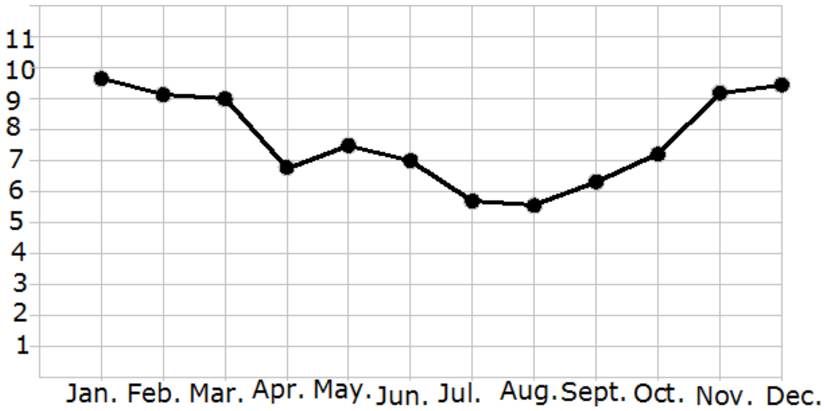


Figure 3: Monthly sunshine hour (average) of Awassa.

From Table 2and graph in Figure 3, Awassa has maximum sunshine hour in months, January, March, November and December, however, the least sunshine hour is in July and August. But the amount of sunshine in each month average implies there is intense sun shine per month which is greater than 6 hours per a day.

Street orientation of Awassa

The city of Awassa has a grid iron street pattern and it orientation is described below as shown on a map Figure 4.

From the total of 882 roads identified 40.47% of roads are oriented to NNE-SSW and 39.00% are to NWW-SEE. Generally 79.81% of existing streets in Awassa are oriented NNE and SEE. This layout or orientation causes NWW, SEE, NNE and SSW oriented buildings.

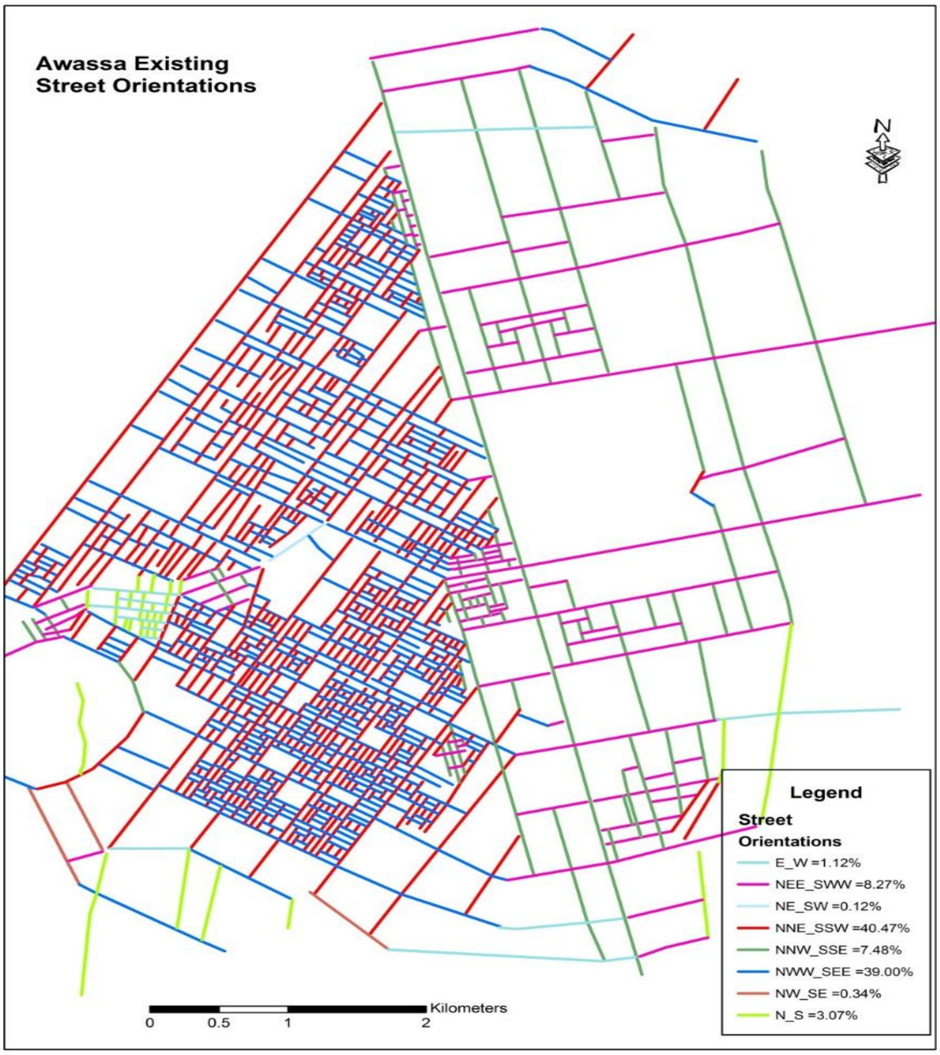


Figure 4: Identified street orientation map of Awassa.

Sun path of Awassa

The sun path of Awassa city for seven months of the year is calculated using the soft wares such as Ecotect, Sun Time, and Excel is in Table 3.

Table 3: Sunrise and sunset Awassa.

		Azimuth (Az)		Hour (h)		Altitude (Al)	Hour (h)	
Months	**Declination (D)**	**Sunrise (°)**	**Sunset (°)**	**Sunrise AM**	**Sunset PM**	**Solar noon**	**Midday PM**	**Day Length**
★**December 22**	-23.48	113.69	246.31	6:33:10	6:16:20	59.02	12:24:45	11:43:10
January 22	-19.97	110.14	249.86	6:44:09	6:31:24	62.53	12:37:45	11:47:15
February 22	-10.89	100.99	259.01	6:41:13	6:38:04	71.61	12:39:36	11:56:51
● **March 22**	0.00	90.00	270.00	6:29:18	6:36:46	82.50	12:32:59	12:07:28
April 22	11.95	77.94	282.06	6:15:02	6:34:19	85.55	12:24:38	12:19:16
May 22	20.39	69.44	290.56	6:08:36	6:37:04	77.11	12:22:48	12:28:28
▬ **June 22**	23.50	66.30	293.70	6:12:06	6:44:13	74.00	12:28:09	12:32:08

Above *Table 3* star, circle and rectangle represents the shortest, equal day & night and longest day of the year.

For the spring equinox March 22, the declination (D) is 0, the sun rises at 90^0 and sets at 270^0, from north east to east west that is equal day and night. But for summer and winter solstice June 22, and December 22, declination (D) is $+23.5^0$ and -23.5^0 respectively. That is December has shortest day and longest night. In December and June Awassa experiences 11:43:10 and 12:32:08 shortest and longest day of the year respectively. Using Equation 7, the sun path diagram of Awassa is drawn as shown below Figure 5.

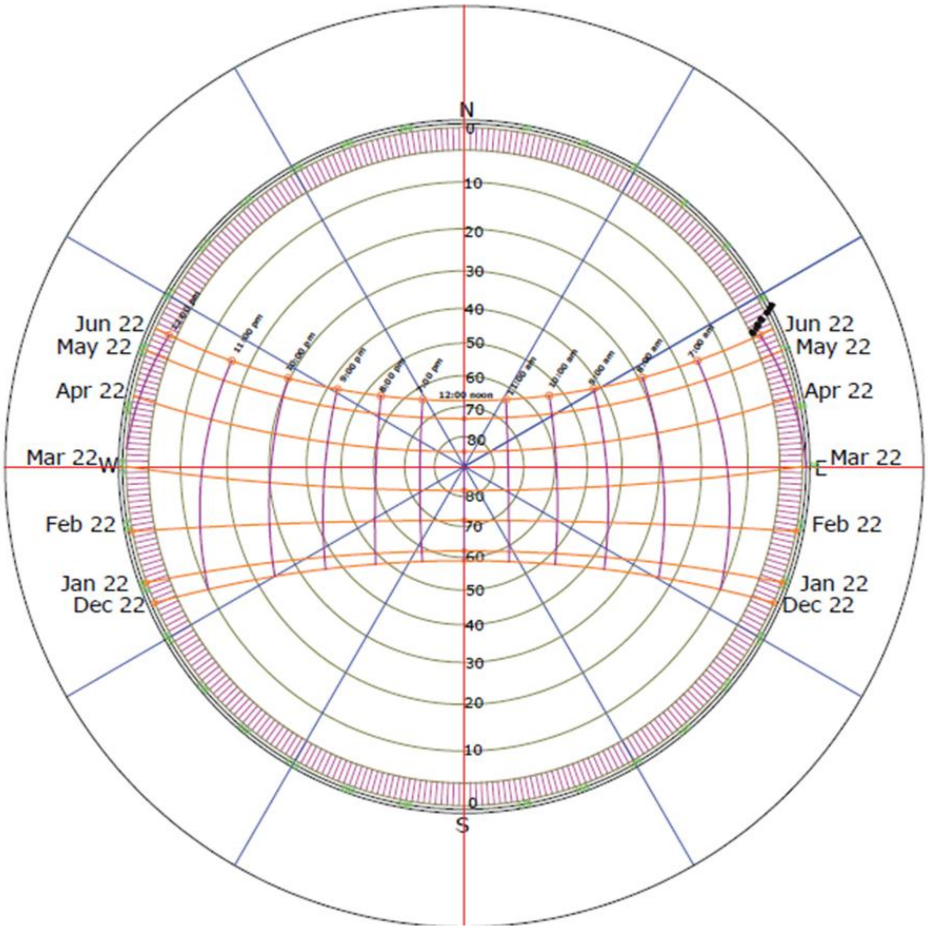


Figure 5: Sun path diagram of Awassa.

Using this sun path diagram Figure 5 Awassa, the shadow length of each street and building is analyzed for every hours of seven months described in Table 3. A unit cube is taken as a gnomn and the right of way is of the width of existing and planned streets of Awassa is taken as the minimum width between buildings and situated either side of the street that cast their shadow on the streets. The critical time in Awassa observed from 4:00-100: o'clock local time. The complete analysis of Awassa streets and Building for single unit is shown in blow illustrations.

Table 4: Common data for streets or Key or legends.

Vertical columns			
A	**B**	**C**	**D**
Street = E-W Building = N-S and S-N faced	Street = N-S Building = E-W and W-E faced	Street = NE-SW Building = NW-SE and SE-NW faced	Street = NW-SE Building = NE-SW and SW-NE faced
E	**F**	**G**	**H**
Street = NNE-SSW Building = NWW-SEE and SEE-NWW faced	Street = NNE-SSW Building = NNE-SSW and SSW-NNE faced	Street = NNW-SSE Building = NEE-SSW and SWW-NEE faced	Street = NEE-SWW a Building = NNW-SSE and SSE-NNW faced

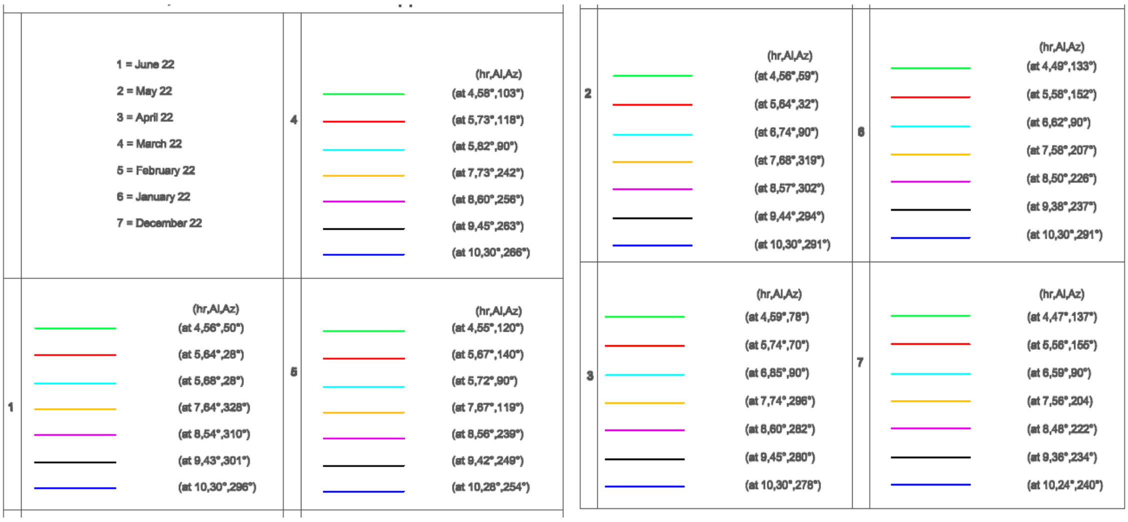
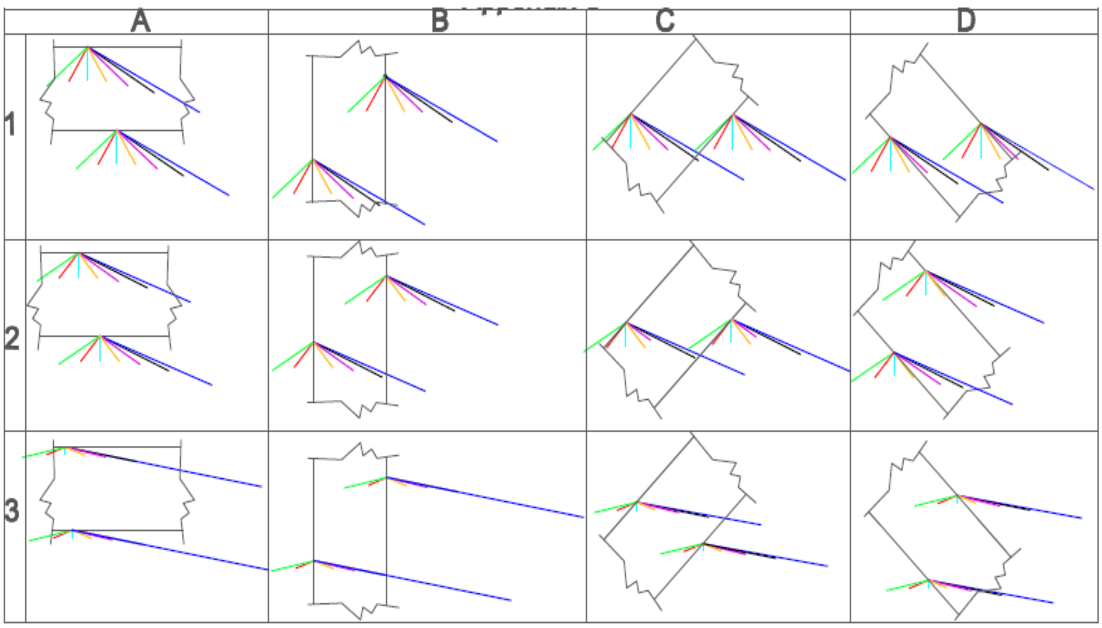


Figure 6: Color, altitude and azimuth codes for street type A-H analyzed.



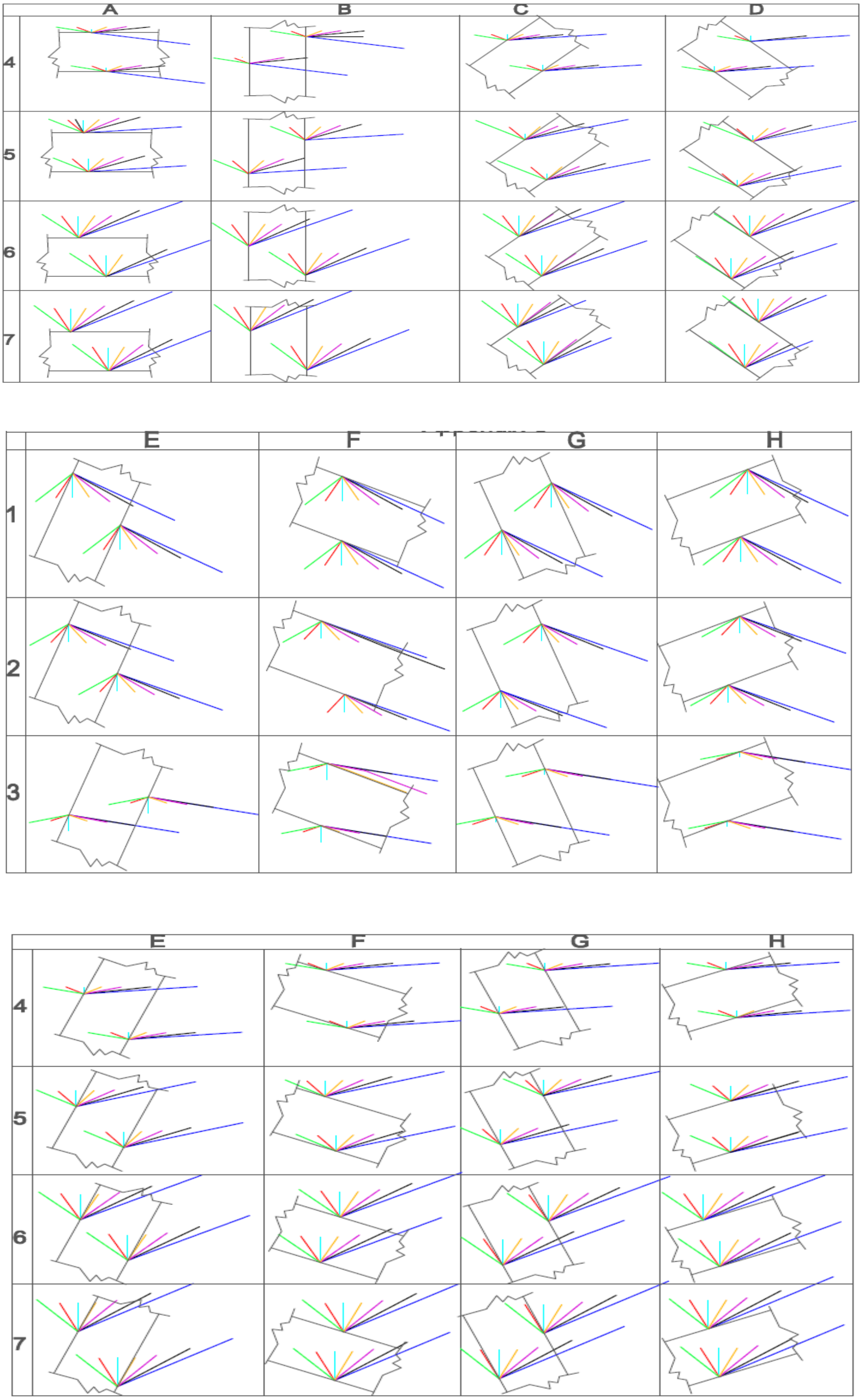


Figure 6: Shadow cast building from 4:00-10:00 o'clock 8 cardinal oriented street for 7 months.

From the Figure 6, the E-W street is getting shade from building north of the street. Building on south side of the street never cast the shade on the street. To get shade on this street critical time 6 and 7 o'clock the street width could be the length of shadow time's height of the building. Which is for a unit cub width of the street at 6 & 7 is equal to 0.39*H and 0.48*H respectively. However, from north to south street both buildings have equal important looking Figure 6 left side. At 6 o'clock on this street the shadow length is parallel to the street, except 6 o'clock the street has enough shadow for full day from right and left side of the buildings. This explanation is clearly seen for all streets and buildings as mentioned on Figure 6 clearly. The shadow length of buildings in eight cardinal direction of street from 4 to 10 o'clock local time for seven months are as following Table 5. The shadow length is calculated for a unit cube of a gnomn which concludes the general.

Table 5: Shadow length of critical times of Awassa.

Month	4:00	5:00	6:00	7:00	8:00	9:00	10:00
June	0.76	0.49	0.39	0.49	0.76	1.07	1.73
May	0.66	0.40	0.29	0.40	0.66	1.03	1.65
April	0.60	0.26	0.08	0.26	0.60	0.98	2.75
March	0.63	0.28	0.08	0.28	0.63	1.03	1.75
February	0.70	0.42	0.32	0.42	0.70	1.07	1.73
January	0.87	0.62	0.52	0.62	0.87	1.28	2.05
December	0.93	0.67	0.59	0.67	0.93	1.37	2.06

From the *Table 7* and above discussions Table 5 about Awassa, orientation can be summarized as follows. Street orientations of N-S, NE-SW, NW-SE, NNE-SSW, and NNW-SSE are comfortable with the length of shadow given for each critical time interval times the height of building both sides which are casting shadow on the street.

The same process and way was used for these cities (Hossaina, Sodo and Tepi), their comparisons were shown in Table 6.

Table 6: Comparison of altitude azimuth for selected cities.

Months		**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**
June	Awassa (Az , Al)(^{0})	61,51	50,64	90,72	335,80	309,63	298,50	294,37
	Hossaina (Az, Al)(^{0})	62,51	51,63	90,73	336,73	309,63	298,51	294,37
	Sodo (Az, Al)(^{0})	61,50	50,62	90,72	338,72	310,63	299,51	294,37
	Tepi (Az, Al)(^{0})	63,48	53,61	90,70	344,73	312,64	300,53	295,39
March	Awassa (Az, Al)(^{0})	97,51	106,66	90,72	224,80	253,67	261,53	265,38
	Hossaina (Az, Al)(^{0})	99,51,	106,65	90,71	219,80	252,68	260,53	264,39
	Sodo (Az, Al)(^{0})	98,51	105,65	90,73	222,81	253,68	261,53	265,39
	Tepi (Az, Al)(^{0})	98,48	104,64	90,72	208,82	250,70	259,54	264,40
December	Awassa (Az, Al)(^{0})	132,43	147,53	90,59	196,58	217,52	230,41	238,29
	Hossaina (Az, Al)(^{0})	132,43	146,52	90,58	194,58	216,52	229,41	238,29
	Sodo (Az, Al)(^{0})	131,43	146,53	90,59	195,59	216,52	230,42	238,30
	Tepi (Az, Al)(^{0})	130,41	143,51	90,58	193,59	214,53	228,43	237,31
Shadow length	For all cities because altitude variation minimized							
June		0.76	0.49	0.39	0.49	0.76	1.07	1.73
March		0.63	0.28	0.08	0.28	0.63	1.03	1.75
December		0.93	0.67	0.59	0.67	0.93	1.37	2.06

This Table 6 is for three months which are June, March and December where longest, equal and shortest day lengths of the year. The shadow length of critical time is also mentioned on the table for these three months. The conclusion from this table for eight cardinal street and sixteen building orientation shown as below Table 7.

Table 7: Summary of street and building orientation of respective city from shadow length in Figure 6 and above Table 6.

Road direction	**Months**						
	June (getting shadow)	**May (getting shadow)**	**April (getting shadow)**	**March (getting shadow)**	**February (getting shadow)**	**January (getting shadow)**	**December (getting shadow)**
E-W	N side bldg.	N side bldg.	N side bldg.	N side bldg.	N side bldg.	N side bldg.	N side bldg.
N-S	Both side bldg.	Both side bldg.	Both side bldg.	Both side bldg.	Both side bldg.	Both side bldg.	Both side bldg.
NE-SW	NE side bldg.	NE side bldg.	NE side bldg.	NE side bldg.	NE side bldg.	NE side bldg.	NE side bldg.
NW-SE	NE side bldg.	NE side bldg.	NE side bldg.	NE side bldg.	NE side bldg.	NE side bldg.	NE side bldg.
NNE-SSW	NNW side bldg.	NNW side bldg.	NNW side bldg.	NNW side bldg.	NNW side bldg.	NNW side bldg.	NNW side bldg.
NWW-SSE	NNE side bldg.	NNE side bldg.	NNE side bldg.	NNE side bldg.	NNE side bldg.	NNE side bldg.	NNE side bldg.
NNW-SSE	Both side bldg.	Both side bldg.	Both side bldg.	Both side bldg.	Both side bldg.	Both side bldg.	Both side bldg.
NEE-SSW	NNW side bldg.	NNW side bldg.	NNW side bldg.	NNW side bldg.	NNW side bldg.	NNW side bldg.	NNW side bldg.

DISCUSSIONS

Using shadow length, altitude and azimuth for critical times from 4:00-10:00 o'clock we can graph the relation for three months June, March and December for 7^0N latitude Awassa the same for the rest three cities (Hossaina, Sodo and Tepi). From this point of view the comfort street relation of Azimuth, Altitude and shadow length can be as following discussion for three months (June 22, March 22 and December 22).

Table 8: Azimuth, altitude and shadow length of June 22.

June 22	Azimuth	Altitude	Shadow length
4	61	51	0.76
5	50	64	0.49
6	90	72	0.39
7	335	72	0.49
8	309	63	0.76
9	298	50	1.07
10	294	37	1.73

From Table 8 the shadow length 4 o'clock to 10 o'clock was different but for the critical time as researcher identified 6 and 7 o'clock, it is short. From the time interval given (4:00-10:00) hours local time more critical time is the shortest shadow length which means both street and building is not get shadow Then relating altitude and azimuth for June 22 represented graphically as.

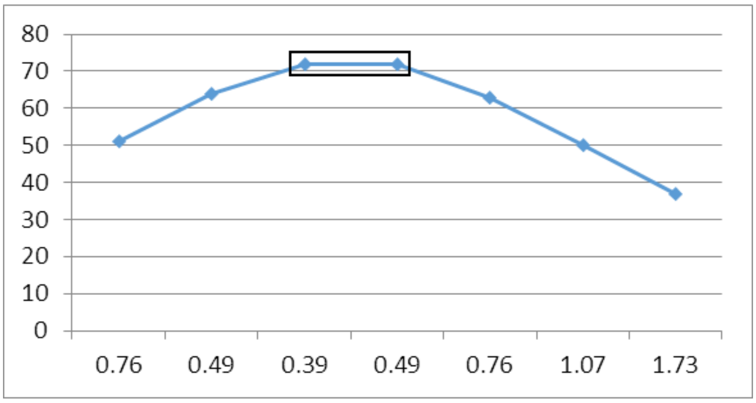


Figure 7.

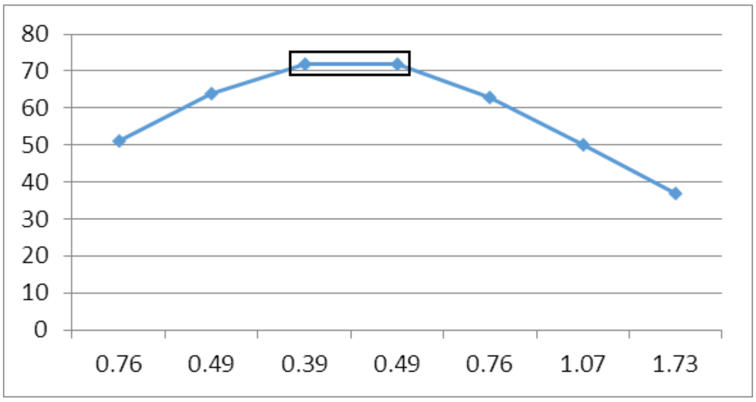


Figure 7: Graphical of critical time for June 22.

From the graph on Figure 7 and Table 8 the shortest shadow length is at a time = 6 o'clock which is 0.39 unit. So the relation f (6) = (0.39, 72) and f (7) = (0.49, 72) so the slope of the graph is 0 because the y value is (72-72 = 0) and the graph at appoint where the time is 6 and 7 is a horizontal line. This determines the direction of shadow from north direction and indicates the shadow is parallel to the street.

Table 9: Azimuth, altitude and shadow length of March 22.

March 22	Azimuth	Altitude	Shadow length
4	97	51	0.63
5	106	66	0.28
6	90	72	0.08
7	224	80	0.28
8	253	67	0.63
9	261	53	1.03
10	265	38	1.75

The same as with earlier Table 8, shadow length of critical time 6&7 o'clock is shorter than these of other hours.

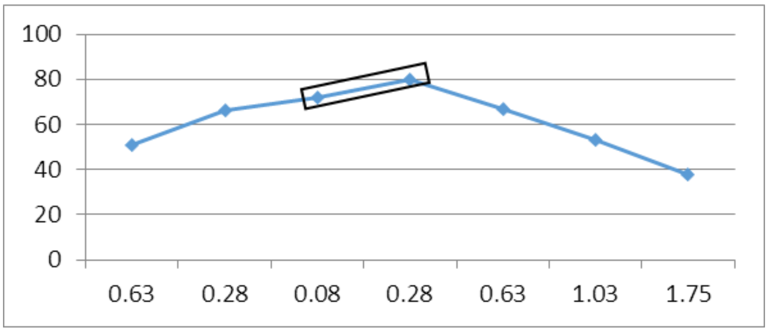


Figure 8: Graphical of critical time for March 22.

From the graph on Figure 8 and Table 9 the shortest shadow length is at a time = 6 o'clock which is 0.08 unit. So the relation f(6) = (0.08,72) and f(7) = (0.28,80) so the slope of the graph is 40 calculated by a formula $m = \{\frac{80-72}{0.28-0.08}\}$ and it is positive. This indicates the shadow of March 22 at 6 o'clock east direction of north.

Table 10: Azimuth, altitude and shadow length of December 22.

December 22	Azimuth	Altitude	Shadow length
4	132	43	0.93
5	147	53	0.67
6	90	59	0.59
7	196	58	0.67
8	217	56	0.93
9	230	41	1.37
10	238	29	2.06

Using the same illustration with above time shadow, azimuth and altitude relation represent as follows for December 22.

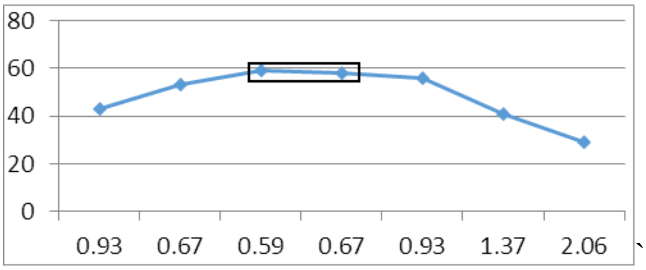


Figure 9: Graphical of critical time for December 22.

From the graph on Figure 9 and

Table ***10*** the shortest shadow length is at a time = 6 o'clock which is 0.59 unit. So the relation f(6) = (0.59,59) and f(7) =(0.67,58) so the slope of the graph is -12.5 calculated by a formula $m = \{\frac{58-59}{0.67-0.59}\}$and it is negative. Which indicates the shadow of December 22 at 6 o'clock is at west side of north.

CONCLUSIONS

1. The best orientation for Awassa, Sodo, Hossaina and Tepi were NNE-SSW and NNW-SSE street orientation and the possible orientations were N-S, NE-SW, NW-SE and. This sentences also concludes the street orientation for whole SNNPR cities of latitude 6^0 and 7^0 N.

2. The effectiveness of existing street orientation for selected cities concluded that: Awassa 48.52%, Sodo 24.2%, Hossaina 25.3% and Tepi 26.1% of street were highly exposed to sun or uncomfortable to users. Streets which were highly exposed to sun E-W, NWW-SEE and NEE-SWW oriented. Buildings in these cities (Awassa, Sodo, Hossaina and Tepi) oriented to S-N and NW-SE are directly exposed to the sun over a year.
3. The shadow length of Awassa, Sodo, Hossaina and Tepi for seven months June, May, April, March, February, January and December from the time interval 4:00-10:00 o'clock is summarized as the following Table 11. Since the comfort of human need from solar radiation is the amount of sun ray blocked by any object like building, tree or other object that determines the width of street is given by:

   $SW = SL * H$ (8)

Where SW is comfort street width, SL is shadow length and H is the height of building or tree.

In the next Table 11 length of shadow given by n unit is only for a unit cub of a ginomn and the proportion for any height is the result of the same factor.

Table 11: Summary of comfort street width.

Month	Comfort street width (SL*H)						
	4:00	5:00	6:00	7:00	8:00	9:00	10:00
June	0.76 H	0.49 H	**0.39 H**	0.49 H	0.76 H	1.07 H	1.73 H
May	0.66 H	0.40 H	**0.29 H**	0.40 H	0.66 H	1.03 H	1.65 H
April	0.60 H	0.26 H	**0.08 H**	0.26 H	0.60 H	0.98 H	2.75 H
March	0.63 H	0.28 H	**0.08 H**	0.28 H	0.63 H	1.03 H	1.75 H
February	0.70 H	0.42 H	**0.32 H**	0.42 H	0.70 H	1.07 H	1.73 H
January	0.87 H	0.62 H	**0.52 H**	0.62 H	0.87 H	1.28 H	2.05 H
December	0.93 H	0.67 H	**0.59 H**	0.67 H	0.93 H	1.37 H	2.06 H

RECOMMENDATIONS

- Streets from E-W or W-E are all the year exposed to the sun, which means a man who is waking and deriving on this road is highly exposed diseases caused by UV. So minimizing the street width with required linier formula is recommended$(SW = SL * H)$ stated in equation 10.
- Streets NWW-SEE and NEE-SWW are about 75% of exposed to sun over the year; planting deciduous tree whose radius is not greater than 6m & height about residential building height is recommended. And in this direction constructing houses with self-protected window is preferable to get comfort.

- Buildings to SW, SE, S and SSW facing are recommended to not open large window glazing because the amount of solar radiation received is high.

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