Sun-path model as a simple helping tool for architecture students in understanding saving energy building design

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Abstract. Understanding the sun-path in designing an energy-saving building is essential. Saving energy is approached by daylight provision, which needs access for lighting the room during the day. In some latitudes, the building also needs the thermal mass to warm up the building during the cold time, requiring the sun's heat radiation. The sun path on the regions creates various ways to design buildings. There is multiple architecture software embedding the sun-path feature. However, the software is not easily installed for free, and some other constraints become the challenges for students to learn it. Therefore, this article figures out the project-based learning in utilizing sun path in 3D models for architecture students. The methods comprise the small project designing sun path in 3D models in various latitudes supported by Andrew sun-path software. This study aims to understand the position of the sun throughout the year, which in building design is useful for saving energy in ventilation and lighting applies. The result is the students' knowledge achievement for understanding the sun position and the site and building analysis toward the sun for obtaining the saving energy building design.

1. Introduction

Sun-path is the apparent significant seasonal-and-hourly positional changes of the sun (and length of daylight) as the Earth rotates and orbits around the sun [1]. Understanding the sun path is essential in protecting the environment and saving energy through passive building design. It is closely linked to the actions identified by the World Business Council for Sustainable Development, i.e., to increase and train workforce capacity and to evolve energy-efficient designs and technologies that use passive and active approaches [2]. Sun path is adopted in solar design that architects use at an Early Design Phase (EDP). According to Pfitzner et al. [3], EDP included a cost-benefit analysis of solar solutions that include future building life-cycle considerations. It is about 80% of design decisions affecting a building’s energy performance at the early design stage. Therefore, designing buildings with an initial approach on sun path is essential. It is about 40% of the energy produced worldwide consumed by buildings, equal to 2500 Mtoe "million-ton oil equivalents" per one year [4]. In architecture, the solar design has been adopted in some software to predict energy use in the building. Nowadays, the 3D solar machine has also been developed, which can give a good insight for predicting the daylight entering the building at any particular time. However, technology runs sometimes much faster than what we have prepared. Sometimes the lack of ability to run the technology or the availability to have the technology become the problem.

In this study, we conduct project-based learning (PjBL) on understanding the sun path related to saving energy building design. The project developed a simple 3D model of sun path in maquette form, designed in some latitudes. The 3D design is proposed to make the students easier to understand the
sun's way of illuminating the room. This study also creates knowledge for developing an understanding of the sun position and the site and building analysis toward the sun for obtaining the saving energy building design. The sun-path also develops the students' insight and creativity in designing apertures for daylight access or, conversely, avoiding excessive sun heat during summer or hot climate by providing shadings or building masks. Project-Based Learning (PjBL) is one of the learning models appropriate for learning with the specific product as an output, such as creating learning media. This model is suitable for students from the elementary school level to the university level [5, 6]. PjBL accommodates students to understand the concept and prior knowledge to obtain the skills by creating the project [7].

1.1 Sun path and solar design
Sun path related to buildings has been previously well-known studied by Szokolay [8], who worked with the northern hemisphere and Nobert Lechner [9] on the southern hemisphere. The use of a sun-path diagram is that the solar azimuth and the altitude can be read, and therefore the position can be precisely determined. By identifying the solar-windows of a particular location, one can design the building such that there is the maximum utility of the solar energy by placing thermal mass required for indirect heat gain in the right orientation. The building meets the visual and thermal comfort level by tracing down the surface area illuminated to apertures' location. Shading devices also can be designed similarly [10].

In understanding the sun-path, some diagrams would identify the sun's positions. The most popular ones are polar and cartesian sun path diagrams. Polar sun path diagrams are designed following the scale of altitude circles. Polar sun path has azimuthal, altitude, date and month, and hour lines [10]. Azimuthal lines are angles running around the edge of the diagram in 15° increments. A point's azimuth from the reference position is measured in a clockwise direction from True North on the horizontal plane. True North on the stereographic diagram is the positive Y-axis (straight up) and is marked with an N. While altitude lines are represented as concentric circular dotted lines that run from the center of the diagram out, in 10° increments from 90° to 0°. A point's altitude from the reference position is measured from the horizontal plane up. Date and month lines represent the sun's path through the sky on one particular day of the year. They start on the eastern side of the graph and run to the western side. There are twelve of these lines shown for the 1st day of each month. The first six months are shown as solid lines (Jan-Jun), while the last six months are shown as dotted (Jul-Dec) to allow a clear distinction even though the sun's path is cyclical. Hour Lines represent the sun's position at a specific hour of the day, throughout the year [10] (see Figure 1).

1.2 Sun path projections
The sun path projections are classified into three types: spherical, equidistant, and stereographic [11], as shown in Figure.

• Spherical (Orthographic) :
  In this method, the radial distance from the center is the cosine of the altitude angle. This sun-path diagram is utilized in making the sun-path 3D model.

• Equidistant
  In this graphic, the radial distance is simply a linear factor of the altitude angle. Thus the relative change in radius between all angles is the same.

• Stereographic.
  This graphic is a more complicated projection in which azimuth lines are first projected back to a reference point located a distance of 1 radius beneath the circle center. The point where each of these lines intersects the zero axis gives the radial distance.
2. Method
This study is a descriptive study based on the observation of the sun-path workshop. The study aims at expressing the implementation of project-based learning (PjBL) based on the sun-path models designed. The study involved 24 architecture students of Universitas Syiah Kuala from Architectural Science class. Those students are divided into four groups, which refer to 4 zones of latitude range based on sun climate, as shown by Figure 2. Those ranges are tropical zone (23.5°N-23.5°S); Subtropic zone (23.5°N-40°N and 23.5°S-35°S); Tempered zone (40°N-60.5°N and 35°S-66.5°S); and cold zone (60.5°N-90°N and 66.5°S-90°S). Each group performs four sun-path models based on the latitude zones. This grouping zones will give an understanding of the participants where the sun path runs on each latitude zones.

In this study, the PjBL procedure comprises:

a. Introductory about the sun path to the students. In this case
b. The preparation for designing sun path 3D models
c. The making process of sun path models
d. Examining the result
e. Evaluation

Figure 1. Polar sun path [11].

Figure 2. Climate zones [12].
3. Results and discussion

This study applied the project in March 2020 for about three times of meetings. In the first meeting as the 1st procedure, we introduced the students about the sun path and its eligibility to save energy building design. In this time, as previously mentioned, we divided the students into four groups of latitudes. In week two, we performed the 2nd procedure that the students brought all stuff for designing the sun path models. The steps of developing sun path models adopt the directions from a book Heating, Cooling, and Lighting for constructing a sun-path model [9]. We asked the students to prepare the board as a base (65mm thick), and three pipe cleaners, or two chenille pieces soft wire, such as copper or aluminum. Procedure 3, namely the making process, was conducted on three steps. The first step was to copy or draw the orthographic projection closest to the latitude of interest and glue it on a piece of foam board of the same size (see Figure 3).

The size of the model is 30cm in diameter. In modeling the 3D sun-path model, we use orthographic to identify the sun path and locate the wire on the model. The orthographic sun path is similar to the spherical sun path, which shows how points of the hemisphere (shown at 150 altitude increments) would be projected onto the horizon plane, giving the positions of the corresponding altitude circles on the horizon plane [8] (see Figure 4).

Step 2 requires students to cut a deep slit from A to B on the projections' north-south line. Then they support quadrant on a piece of reasonably thick transparent plastic film Trace the support quadrant on the part of fairly thick transparent plastic film (see Figure 5).

![Figure 3. The students drawing the Orthograpic sun path.](image1)

![Figure 4. Orthographic projection](image2)

Source [8]
Figure 5. The Installation of the support quadrant for defining the annual sun path.

The support quadrant loads the sun path annual shiftings i.e. mid-summer, equinox, and mid-winter (see Figure 6). On equinox days the sun appears to rise at due east and set at due west, (at exactly 6:00 and 18:00 h respectively) and at noon it reaches an altitude of $\text{ALT} = 90 - |\text{LAT}|$, i.e. a position when the zenith angle is the same as the latitude ($\text{ZEN} = |\text{LAT}|$). Here LAT is taken as its absolute value. At mid-summer noon the sun would be 23.45° higher ($\text{ZEN} = \text{LAT} - 23.45°$ or $\text{ALT} = 90° - \text{LAT} + 23.45°$). At mid-winter 23.45° lower: $\text{ZEN} = \text{LAT} + 23.45°$ or $\text{ALT} = 90° - \text{LAT} - 23.45°$.

Figure 6. The sun path annual shiftings of Bandung.

As an example, Bandung city was identified through its latitude i.e., 6,9175°S (see figure 7). The students defined the mid-winter, equinox, and mid-summer lines (annual shiftings) based on the latitude.

- **Mid-winter**: 90°- 6,9175°S- 23.45°N (to the north) : 16,53°N
- **Equinox**: 90° - 6,9175°S (to the north) : 83,082°N
- **Mid-summer**: 90°- 6,9175°S + 23.45°S (to the south) : 73,47°S

Step 3, the students insert three wires on the three annual shiftings. They bend the first wire on the equinox across the support quadrant and add the others end in the sunset hole. Then they repeat this procedure for the other two sun paths.
Figure 7. The installation of the wire on three sun paths.

| Latitude       | orthographic | Sun path model (macquette) | 3D sun path |
|----------------|--------------|----------------------------|-------------|
| Bandung        | ![Bandung Orthographic](image1.png) | ![Bandung Sun Path Model](image2.png) | ![Bandung 3D Sun Path](image3.png) |
| Jeddah         | ![Jeddah Orthographic](image4.png) | ![Jeddah Sun Path Model](image5.png) | ![Jeddah 3D Sun Path](image6.png) |
| Wellington     | ![Wellington Orthographic](image7.png) | ![Wellington Sun Path Model](image8.png) | ![Wellington 3D Sun Path](image9.png) |
| Newcastle      | ![Newcastle Orthographic](image10.png) | ![Newcastle Sun Path Model](image11.png) | ![Newcastle 3D Sun Path](image12.png) |

Figure 8. Sun path diagram 3D models on various latitudes designed by the students.
The sun-path influences the architecture through the daylight access and the shadings. Since the sun path diagram was made on a small scale, which is about 30 cm in diameter, therefore the building model should be made in a very tiny size for modeling daylight access and shading. Instead of modeling the small scale of building maquette, the students are directed to use the free application of sun path, i.e., Andrewmarsh sunpath3, for keeping students understand about the further use of sun path in building design.

As procedure four, which aims at examining the result, the application of Andrewmarsh sunpath3 [13] guided the students to understand how the sun path creates the shadings as shown by Figure 8. As we divided the groups into four latitude ranges referring to the specified climate zones, we took four samples representing those latitudes. Figure 8 shows the sun path diagram 3D models on various latitudes designed by the students combined with the orthographic sun path and the 3D model sun path software. The 3D model of shadings is setting simultaneously as a solar time on 21 March 2020 at 15.02.

a. **Bandung (tropical zone).**
Bandung is located at 6,9175° N latitude. It has a warm-humid climate, which is high in Relative Humidity. The latitude shows the location which is close to the equator. Being close to the equator will give the not significantly different sun running hours on its path throughout the year. Figure 8 shows that the afternoon shading in Bandung at 15.02 is precisely near the east. Conversely, in the morning, the shading will go to the west. The equator's position gives the high radiation, which is straight from the east and the west. Therefore, we recognize that the traditional tropical house has more apertures, such as windows on the southern and northern side, aiming to achieve sunlight without excessive heat.

b. **Jeddah (subtropic zone).**
Jeddah is located at 21,32° N latitude. The city, located in Saudi Arabia, has an arid climate assigned to extremely hot weather during summer. Due to the arid and desert environment, the shading against the sun is essential for creating a thermally comfortable microclimate. The sun path performs the shortest day that occurs in December and January. During these months, the shading will depend more on the northern side. The longest day is in September, which has the shading just close to the east and the west.

c. **Wellington (tempered zone)**
Wellington is located at 41, 2865° S. The position on the southern atmosphere gives access to the sunlight on the northern side. The region has the summer and most extended daytime in January and December, which contrasts with the north atmosphere. Therefore, the shading works more on the southern side (south-west, south, south-east) (see Figure 8). This recommends creating more apertures on the north side of the buildings for giving optimal daylight.

d. **Nuuk (cold zone)**
Nuuk is located at 64,18°N. This region has a more cold time throughout the year. Due to the position on the northern side, Nuuk sees the sun path on the southern side. Therefore, the buildings are built with more openings on the south of sides to get the daylight. The sun only appears best in June and July, while in January and December, no daylight is performed.

Here the students can understand that the place in the northern atmosphere will see the sun at the southern atmosphere and vice versa. The shading positions will figure out where the buildings' openings or apertures should be located for obtaining daylight. The students also could understand why the buildings in the northern part, which have latitude more than 40°N tending to have more cold times, should orient the large aperture to the south. The orientation will give plenty of daylight and create a passive heating design. Directing building opening to the north will cause a lack of daylight and invite freezing wind from the north pole. The latitude toward the south pole vice versa should orient the building apertures toward the north. The objective is to avoid the cold breeze from the south and gain precious daylight from the north.

In comparison, the buildings located in the sub-tropic zone (LAT: 23.5-40°S/N) are built typically with small openings, compact, and dense with other buildings. Small apertures aim to avoid the excessive solar radiation and gain more shades by the dense buildings nearby. Tropic zone ranges in
latitude 0-23.45° S/ N suffers direct solar radiation from west to east on the equator. Tropics also have an ample amount of rains annually and high relative humidity. Therefore the buildings are recommended to have large openings toward north and south for gaining undirected sun radiation and air circulation for reducing the relative humidity.

4. Conclusion
The article presents the study on the sun-path diagram related to building design. It is developed on Project-Based Learning, i.e., a workshop involving Architecture students of Universitas Syiah Kuala. The workshop taught the students that the sun path on various latitudes would create different daylight access and shadings. The workshop guided the students to create a 3D model of sun path diagram. The model also gives insight the closer the latitude toward the north or the south pole, the further the equator's zones. The northern latitudes should orient the opening to the south and vice versa, aiming to deliver more access to daylight. In building design, it is useful for saving energy in receiving the light throughout the day. The sun path's 3D model will create a more understanding of the sun path and its relationship with building design. This learning method is straightforward to be made and learn compared with the paid software embedding the sun-path application. The software usually takes time to learn and run. The cost of registering and installing the program is also high. Therefore, the 3D model of sun-path would be a helpful tool for studying and understanding the sun-path in architecture.

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