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An Experimental Study on the Effect of Surface Orientation and Inclination on Incident Solar Irradiation: Application to Buildings

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ABSTRACT

The study explores the impact of surface orientation and tilt on incident solar irradiation. It was conducted in M'Sila, an Algerian province, from February to June. A number of experiments were carried out using an experimental setup consisting of a heliometer and a slant changer, which allowed for the variation of the tilt angle. Nineteen tilt angles ranging from 0° to 90° were investigated for the four main directions: North, South, East, and West. The obtained outcomes were statistically analyzed. At east and south orientations, incident solar irradiance rose as a function of tilt angle, reaching a maximum at the optimal angle, and then gradually decreased. Generally, the incident solar irradiance decreased as the tilt angle increased in the case of west and north orientations. The tilt angle of the exposed surface as well as the sun's elevation in the sky affected the amount of intercepted energy significantly at each orientation ($p<0.05$). When the sun was low in the sky, the south orientation was most preferred for an inclination greater than or equal to 25°. The north-facing surfaces with steep slopes ($\beta \geq 55°$) received the least amount of solar radiation. These results hold great importance, particularly in the building sector, as they can be utilized to achieve energy saving.

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1. INTRODUCTION

Solar energy is the most environmentally-friendly energy source that can be used to replace conventional energy (Kalogirou, 2004; Ka-LunLau et al., 2017; Chegaar & Chibani, 2001). Many devices have been developed to harness this natural energy, whether in the form of heat (Chegaar & Chibani, 2001; Handoyo et al., 2013) or electricity (Devereux & Cole, 2021; Kousksou et al., 2015). Solar energy also saves energy while protecting the environment in passive buildings.

Due to the shape of the Earth and its movement around its axis and around the sun, many factors affect the amount of solar irradiation that reaches the surface of solar systems, including latitude of the site, day of the year, time of the day, surface tilt angle, and surface azimuth angle (Handoyo et al., 2013). Apart from the design and location of solar systems, the tilt and azimuth angles of the solar exposed surface are two parameters that can be modified to improve the effectiveness of any solar system (Handoyo et al., 2013; Skeiker, 2009; El-Kassaby, 1988). Moreover, the tilt angle (inclination angle β) is the angle formed by the system's solar surface plane and the horizon. The surface azimuth angle (γ), on the other hand, is the angle formed when projecting the normal to the system's solar surface onto a horizontal plane, relative to due south or north.

To collect the maximum solar energy, the system's solar surface (receiving surface) should be perpendicular to the incident solar irradiation; to do so, this surface must follow the sun's movement across the sky. Solar trackers have been developed for this specific purpose (Anshul et al., 2020). However, they come with certain drawbacks, including hot costs, energy consumption for operation, and limited suitability in certain situations (Handoyo et al., 2013; Skeiker, 2009; Elminir et al., 2006). Therefore, setting the solar system at an optimal tilt angle (fixed value) and correcting the tilt on a regular basis is frequently practical (Handoyo et al., 2013; Elminir et al., 2006; Torres & Crichigno, 2015). The optimum tilt angle of a solar system is the angle at which the radiation on its exposed surface is at its maximum for a given day or period.

Data of incident solar irradiation acquired from meteorological stations is always recorded on horizontal surfaces rather than tilted ones. Therefore, in most cases, empirical models are used to determine the radiation incident on tilted surfaces from the radiation incident on a horizontal surface (Basharat et al., 2016; Jakhrani et al., 2012; Shukla et al., 2015). These models calculate beam and ground reflected radiation on a tilted surface using the same method. The only difference lies in the treatment of diffuse radiation (Elminir et al., 2006).

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Optimal tilt angle determination has been the subject of several investigations (Handoyo et al., 2013; Basharat et al., 2016; Ashetehe et al., 2022). The optimal tilt angle can be calculated using a direct formula (Qiu & Riffat, 2003; Hafez et al., 2017; Duffie & Beckman, 1988) or by estimating the incident solar irradiation on tilted surfaces (Calabrò, 2013],[Idowu, 2013; Ihaddadene et al., 2017). The appropriate tilt angle can also be determined through experimentation (Elminir et al., 2006; Ihaddadene et al., 2017). Furthermore, in the literature, numerous optimum tilt angle values for fixed solar systems have been presented, depending solely on the latitude of the installation site (Skeiker, 2009). It is worth noting that the majority of publications discussing the optimal tilt angle have been conducted on surfaces oriented toward the equator (Duffie & Beckman, 1991; El-Sebaii, et al., 2010). Therefore, the ideal orientation of solar systems (optimal azimuth angle) is toward the equator; solar systems in the northern hemisphere should face south, whereas those in the southern hemisphere should face north.

M'Sila is an Algerian province located at latitude 35° 42'07", longitude 4° 32'43", and an elevation of 441 meters above sea level. It receives an average of 1.79 MWh/m^2 solar energy annually (Kherbiche, et al., 2021), with an average day length of 12 hours. Moreover, the duration of a day in M'Sila can vary from 8 hours, 30 minutes, and 36 seconds (the shortest day) to 14 hours, 19 minutes, and 48 seconds (the longest day). M'Sila is well positioned in terms of solar energy potential. The quantitative evaluation of solar irradiation incident on a tilted plane is very important for designing solar energy collecting devices, buildings, and a variety of other structures. This paper aims to study experimentally, for the first time, the simultaneous impact of surface orientation and inclination on incident solar irradiation in the M'Sila region over a period of five months: February, March, April, May, and June. The findings of this study are intended to be applied to the building sector. For the four main directions of North, South, East, and West, 19 tilt angles ranging from 0° to 90° were investigated. Another objective of the current research is to determine the best tilt angle and orientation for this region during the four months of study. In other words, this research represents the initial phase of M'Sila's solar energy exploitation. The present paper follows a structured format, starting with an introduction that provides background information. It then proceeds to explain the methodology employed in the study, present and analyze the obtained results, and discuss their implications. Finally, the document concludes by summarizing the key findings and their significance.

2. MATERIALS AND METHODS

2.1. Experimental and set up

A compass, a slant changer, and a heliometer make up the experimental equipment pieces used to meet the objectives of the current study.

A. *Compass*

A compass is a device that determines orientation in any location by using the four cardinal points (north, south, west, and east). The needle on the compass is always pointing north. The compass used in our case is a digital one, i.e., a downloadable application on a mobile phone and it allowed determining the four primary orientations concerning the site under study.

B. *Slant changer*

The slant changer is a wooden instrument that was made out of a protractor to investigate the impact of surface inclination on intercepted solar energy. As shown in Figure 1, the tilt angle with this instrument can be adjusted in 5° increments from 0° to 180°. Its center has a pivoting axis on which the heliometer (see later) is fixed. This pivot allows varying the tilt angle manually. The variation of the inclination angle is subject to ±1° inaccuracy.

C. *Heliometer*

The instantaneous rate of solar energy intercepted is measured in kilowatts per square meter using a heat flux sensor known as a heliometer. The heliometer utilized is a component of the ET 200 thermal collector, an experimental device made by the German company Gunt (Figure 2).

As illustrated in Figure 2, the measurements from the heliometer are shown on the relevant display screen on the control and command box of the ET 200 thermal collector. More details on the heliometer's operating principle can be found in our later work (Ihaddadene et al., 2018). The use of the heliometer makes it possible to study the effects of surface inclination and orientation independently of their construction materials or surface size. Moreover, incident solar irradiance was measured with ± 0.01 kW/m^2 precision.

2.2. Experimental procedure

To meet the objectives of the current study, the four cardinal points were initially identified using an electronic. These points were then marked on the study site, along with the pivoting support to which the slant changer was attached. The heliometer was then mounted on the pivot of the angle changer, as illustrated in Figure 3. Thus, this design makes it feasible to intercept solar irradiance at different angles throughout the day. Moreover, the pivoting support makes it easy to switch from an east-west orientation to a south-north orientation (Figure 3).

The inclination angle was adjusted from 0° to 90° in 5° steps for each direction, and the incident irradiance was captured by the heliometer, with the measured value shown in kW/m^2 on the control and command box. The measurements were taken every ten (10) minutes from 8:30 a.m. to 4:30 p.m. on five days in 2019: February 27, March 17, April 15, May 15, and June 10.

It is important to note that incident solar irradiance was measured for each experiment within a time frame of less than one minute for all tilt angles (0° to 90°) and orientations. This efficient data collection process validates the research outcomes.

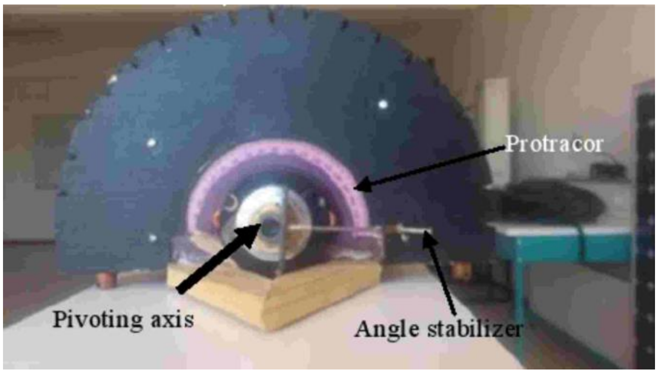


Figure 1. Slant changer (Protractor).

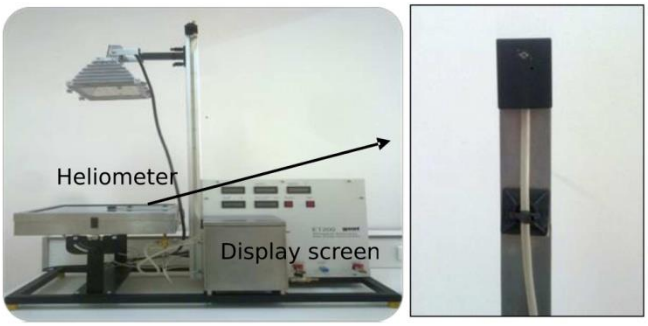


Figure 2. ET 200 Solar collector and heliometer.

2.3. Statistical analysis

The term "statistics" refers to a methodology created by scientists and mathematicians for gathering, organizing, and analyzing data to reach certain conclusion. A variety of statistical tests can be employed depending on the number of groups being compared, the assessment of normality, and the assumption of independence. In this investigation, Friedman's test, a non-parametric test similar to one-way ANOVA with repeated measures, was employed to assess whether there is a statistically significant difference among the means of three or more groups, with the same subjects appearing in each group. The statistical software SPSS 26 was utilized to conduct this investigation based on the significance probability (α=0.05).

Figure 3. Experimental setup.

3. RESULTS AND DISCUSSION

Two aspects were addressed during the course of this study: the effect of orientation and tilt angle on incident solar irradiation, regardless of the nature of the solar exposed surface. Except for February, the days chosen to carry out the experiments correspond to the typical days. In other words, daily extraterrestrial radiation on the selected days is nearly equal to the average monthly extraterrestrial radiation.

Instead of using the azimuth angle (γ) values, we directly employed the orientations themselves in the following analysis. In fact, the azimuth angles are given as follows: γ =0° for the south, γ =90° for the west, γ =180° for the north, and γ =270° for the east.

3.1. Effect of orientation on inident solar irradience

The orientation of solar-exposed surfaces with regard to the four cardinal points affects the amount of energy intercepted. Figure 4 illustrates five examples of incident solar irradiance on a 40° inclined surface directed at the four cardinal points during the five days of study. The incident solar energy is clearly affected by the orientation of the solar exposed surface, as evidenced by different paces obtained at different orientations. In terms of figures, on February 27, for instance, the surface-facing south received the highest amount of solar irradiance, 23.95 kW/m^2, while the north-facing surface received the lowest (8.42 kW/m^2). Furthermore, the east-facing surface received more solar irradiance than the west-facing surface, with values of 20.55 kW/m^2 and 13.43 kW/m^2, respectively.

The oscillations seen on the curves in Figure 4 (dashed black circles) result from cloud passage, which inhibits solar radiation from reaching the earth's surface. Therefore, the experiments were conducted on days with mostly clear skies and brief periods of cloud cover that intermittently obscured the sun.

In the case of a 40° sloped surface, the east-facing surface received more energy in the morning during the five months of testing, while the west-facing surface received the least (Figure 4). This outcome was obtained due to the sun's daily course, which rose on the east side and set on the west. Furthermore, no generalization can be made for surfaces facing the four directions in the afternoon. When the sun is low in the sky during the months of February and March, the south-facing surface receives more energy in the afternoon compared to other directions. Conversely, the north-facing surface receives the least amount of energy during this time (refer to Figure 4).

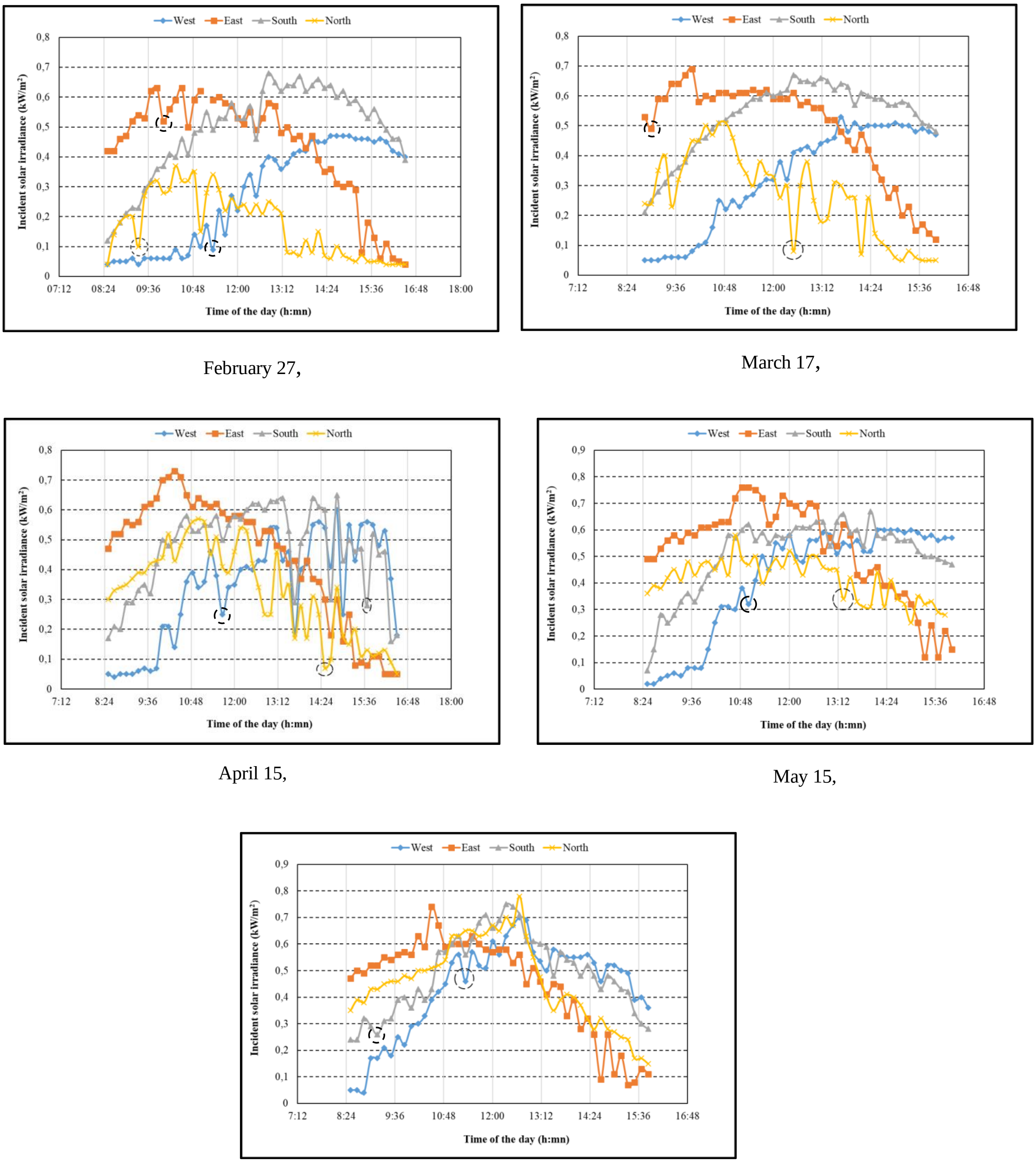
The collected data on the effect of orientation during the test days showed non-normal distribution. In addition, Additionally, the groups representing solar irradiance by direction were paired, as the measurements were taken for the same angle. Hence, the Friedman test—a non-parametric test—was applied in this case to determine if there were differences in measured data based on orientation.

Table 1 displays the Friedman test results for each experiment day. As can be observed, there is a significant difference between the groups since the P-values at all orientations are lower than the significant probability ($p<0.05$), meaning that the surface orientation significantly affects the amount of solar energy received.

Table 1. Friedman test results for the effect of the surface orientation on the intercepted solar irradiance provided by SPSS 26.

	Sampling number	Ch Square	Degree of freedom df	P-value
February 27	19	32,647	3	0.000
March 17	19	27,935	3	0.000
April 15	19	31,210	3	0.000
May 15	19	50,736	3	0.000
June 10	19	11,103	3	0.011

The amount of solar energy intercepted by a surface is affected by not just its orientation but also the sun position in the sky. As shown in Figure 4, when the sun rises higher in the sky from February to June, the curves depicting the daily evolution of the intercepted solar irradiance in the west and south directions tend to converge. The east and north directions exhibit similar patterns of change.



February 27,

March 17,

April 15,

May 15,

June 10,

Figure 4. Incident solar irradiance on a 40° inclined surface directed at four cardinal points during the five days of study.

As known, the sun remains below the equator from September 21 (autumn equinox) to March 21 (spring equinox), passing through December 21 (winter solstice). Hence, during this period, the sun is low in the sky in the northern hemisphere. Conversely, it is above the equator from March 21 to September 21, passing through June 21 (summer solstice), and the sun is high in the sky throughout this time in the northern hemisphere. Furthermore, the sun is at the same level as the equator for the spring and autumn equinoxes. The summer solstice marks the highest altitude of the sun, whereas the winter solstice marks its lowest.

The impact of the sun elevation in the sky on the amount of solar irradiance intercepted at different tilt angles oriented toward the four cardinal points is shown in Figure 5. This latter demonstrates that in addition to the orientation and elevation of the sun in the sky, the inclination angle of the solar exposed surface has an important impact on the amount of solar energy gathered. For example, on February 27, the average incident daily solar irradiance on a surface inclined at 60° and orientated west was 0.22 kW/m^2, while it was 0.33 kW/m^2 on a surface inclined at 20° in the same direction and on the same day.

Results of the Friedman test to determine how the sun position in the sky affected the solar energy intercepted, as shown in Table 2. As can be seen, there is a significant difference in the solar irradiance gathered on different days since the P-values are lower than significance probability ($p<0.05$), indicating that the sun's position in the sky affects the amount of solar energy intercepted significantly.

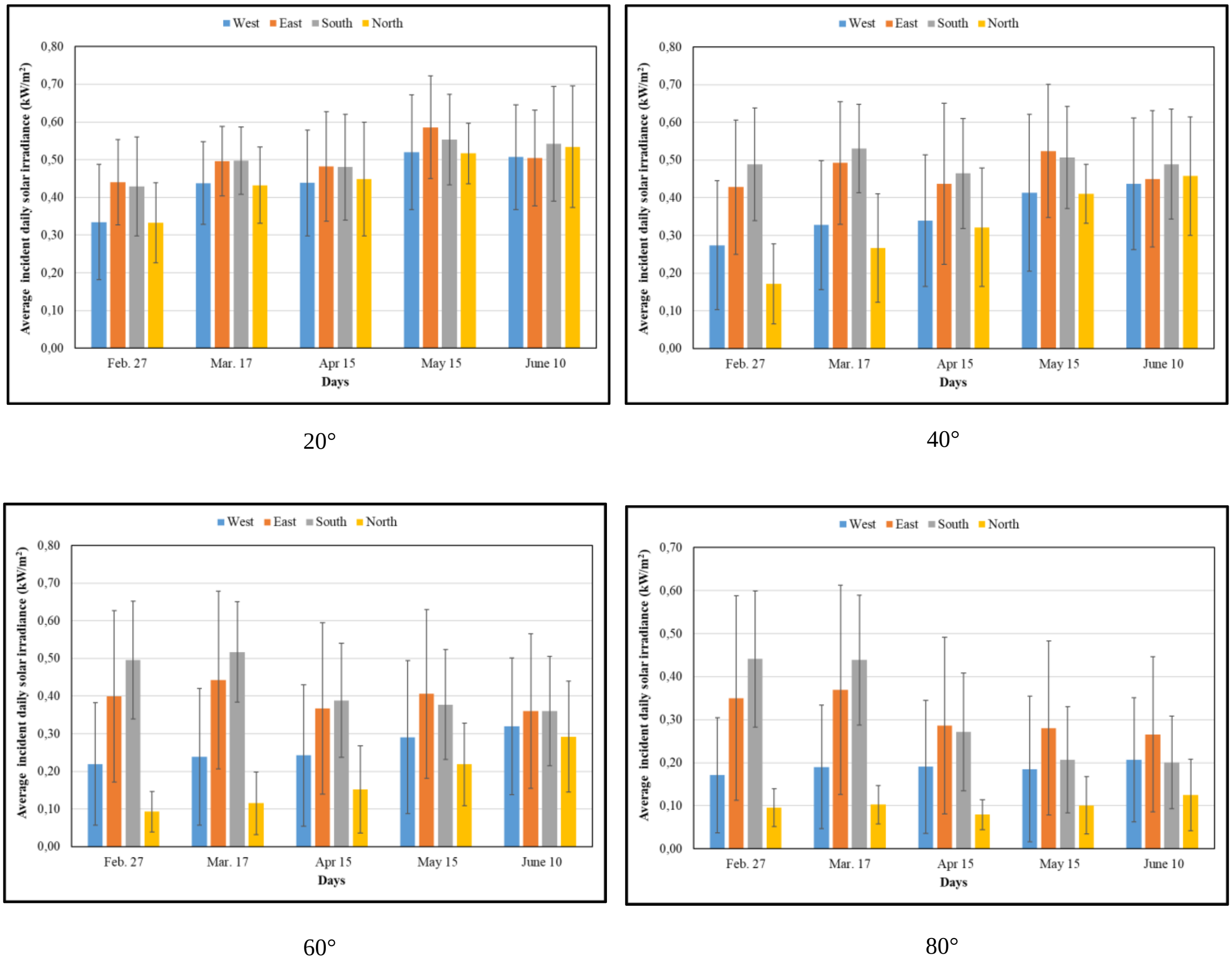


Figure 5. Effect of the sun elevation in the sky on the intercepted solar energy for different orientations and tilt angles

Table 2 differs from Table 1 by presenting a condensed summary of the key points obtained from Friedman's test, achieving a more space-efficient representation.

Table 2. Friedman test results for the effect of the sun's position on the intercepted solar irradiance provided by SPSS 26.

Null hypothesis	Test	P-value	Decision
The distributions of Feb. 27, Mar. 17, Apr. 15, May 15, and June 10 are the same	Two-way analysis of variance by Friedman ranking for related samples	**0.000**	Rejection of null hypothesis

In the case of west-facing surfaces, the impact of the sun elevation in the sky on the intercepted energy is insignificant for inclined surfaces with a tilt angle greater than 75° (Tilt angle of 80° in Figure 5). Indeed, the highest variations in solar irradiance received throughout the test period are less than 21%, 14%, and 9% on sloped surfaces at 80°, 85°, and 90°, respectively. This finding can be applied to the building sector in M'Sila, where the amount of solar radiation hitting west-facing walls (sloped surfaces at 90°) varies slightly (no more than 9%) between February and June. Furthermore, the incident solar irradiance increases with the sun elevation on slanted surfaces between 30° and 70° (Tilt angles of 40° and 60° in Figure 5). The energy collected peaks on May 15 for surfaces inclined from 0° to 25° (tilt angle of 20° in Figure 5). It is worth noting that regardless of the tilt angle, the position of the sun in the sky on March 17 and April 15 had a minor effect ($p = 0.705$) on the amount of energy intercepted in the westerly direction (Figure 5).

For east-facing surfaces, the energy collected peaks on May 15 for surfaces inclined from 0° to 45° (Tilt angles of 20° and 40° in Figure 5) and on March 17 for surfaces inclined from 50° to 90° (Tilt angles of 60° and 80° in Figure 5).

For south-facing surfaces, the energy collected peaks on May 15 for surfaces inclined from 0° to 30° (Tilt angle of 20° in Figure 5) and on March 17 for surfaces inclined from 35° to 75° (Tilt angles of 40° and 60° in Figure 5). Furthermore, the incident solar irradiance decreases with the sun elevation on slanted surfaces greater than or equal to 80° (Tilt angle of 80° in Figure 5). This result may be extended to the building sector in M'Sila, where south-facing walls receive much more solar energy in the winter than in the summer since the sun rays fall on them perpendicularly in the winter and almost parallel in the summer. This experimental outcome is consistent with the calculations achieved for Abu Dhabi by Jafarkazemi et al. (Jafarkazemi & Saadabadi, et al, 2013).

For north-facing surfaces, the incident solar irradiance increases with the sun elevation on slanted surfaces up to 75° (Tilt angles of 20°, 40°, and 60° in Figure 5). On surfaces sloped at angles greater than 75°, low solar irradiation intensities less than 0.15 kW/m^2 were recorded during the test period. North-facing walls, therefore, receive the least solar energy throughout the test period compared to other orientations.

The tilt angle of the exposed surface and the sun elevation in the sky affect the quantity of energy intercepted in each direction. Figure 6 depicts the best orientations found for each month over the trials.

The south is the ideal orientation for very particular angles, not all angles (Figure 6). Indeed, when the sun is low in the sky (as it is in February and March), the south orientation is most favored for an inclination greater than or equal to 25° ($\beta \geq 25°$). When the sun is high in the sky (as it is in April, May, and June), the east direction is preferred for inclination angles more than 75° and less than or equal to 90° ($75° < \beta \leq 90°$). Furthermore, north-facing steeply sloped surfaces ($\beta \geq 55°$) received the least amount of solar irradiation throughout the testing period, whereas low-sloped surfaces ($\beta \leq 5°$) received the highest (except for May).

In reality, there is no discrepancy between our findings and those reported in the literature about the best orientation, which is a southward orientation (El-Sebaii, et al., 2010; Jafarkazemi & Saadabadi, et al, 2013; Gunerhan & Hepbasli, 2007). On an annual basis, as indicated in the literature (Jafarkazemi & Saadabadi, et al, 2013; Gunerhan & Hepbasli, 2007; Li & Lam, 2007), the south is the optimal direction, but not on a monthly scale, according to our findings.

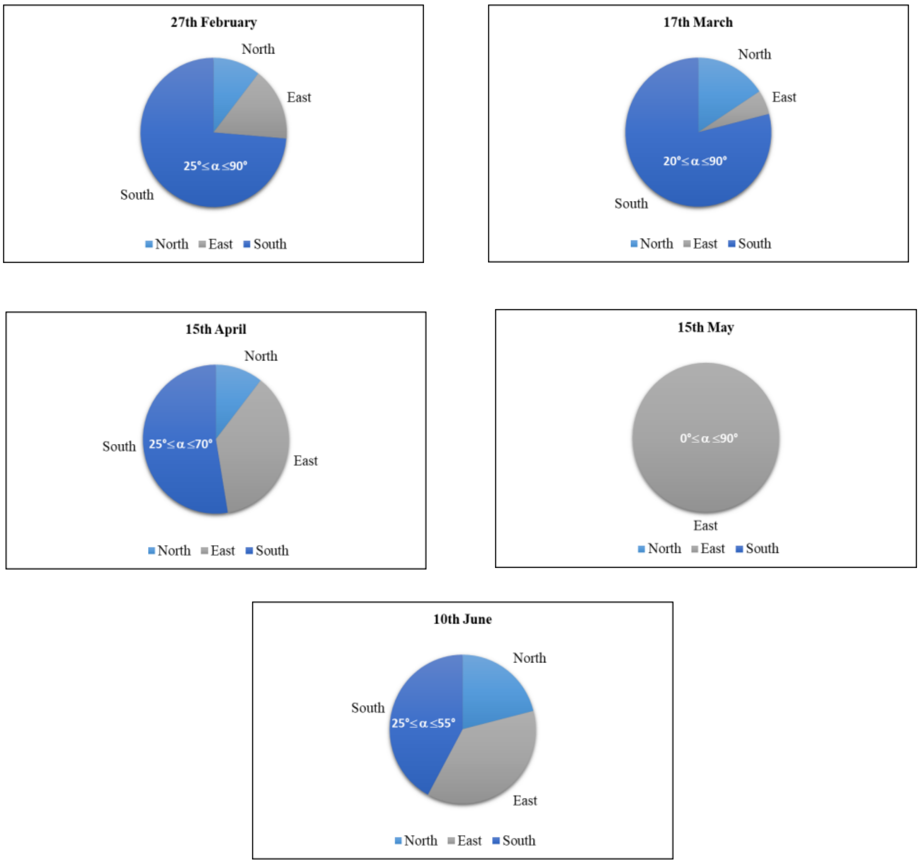


Figure 6. Monthly best orientations.

Furthermore, our experimental study was conducted from February to June. During this period, the south is the best orientation for tilt angles ranging from 20° to 80° (Figure 7). The north direction is the least sunny for tilt angles greater than 25°, as shown in Figure 7.

The findings of the current investigation are extremely significant for the building sector since the monthly solar gain is more interesting than the yearly gain. Fixed solar devices, on the other hand, are more concerned with annual solar gain than monthly gain.

In the building sector, east-facing walls receive more solar energy when the sun is high in the sky than in other orientations. However, when the sun is low in the sky, south-facing walls are exposed to greater solar radiation than walls with other orientations. From February through June, the north-facing walls are the coldest part of the building envelope since they receive the least amount of solar radiation (Figure 7).

3.2. Effect of tilt on inident solar irradience

Figure 8 shows the effect of tilt angle on incident solar irradiance for each of the four orientations throughout the testing period. As can be observed, the incident solar irradiance depends on both the tilt angle and the direction of the exposed solar surface since the pace of the curve representing the evolution of the incident solar irradiance as a function of the tilt angle differs from one orientation to another. It should be noted that the curves illustrating the relationship between incident solar irradiance and tilt angle for various orientations vary with the sun's annual course.

When the solar exposed surface is oriented towards the east, the incident solar irradiance increases with the tilt angle, reaches a maximum, and then decreases (Figure 8). The vertical surface (i.e., slanted 90° to the horizontal) receives the least amount of solar energy regardless of the position of the sun in the sky, which affects the optimal tilt angle. Indeed, the optimal tilt angle for an east-facing surface depends on the sun's annual trajectory (Figure 8).

This finding can be applied to the building sector in M'Sila, where terrace roofs (horizontal surfaces) and roofs (inclined surfaces) that face east get more solar irradiance than east-facing walls (vertical surfaces) from February to June.

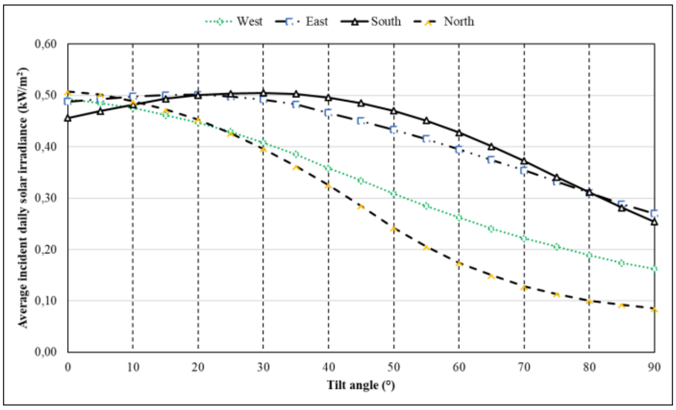


Figure 7. Effect of surface orientation and tilt on incident solar irradiance from February to June.

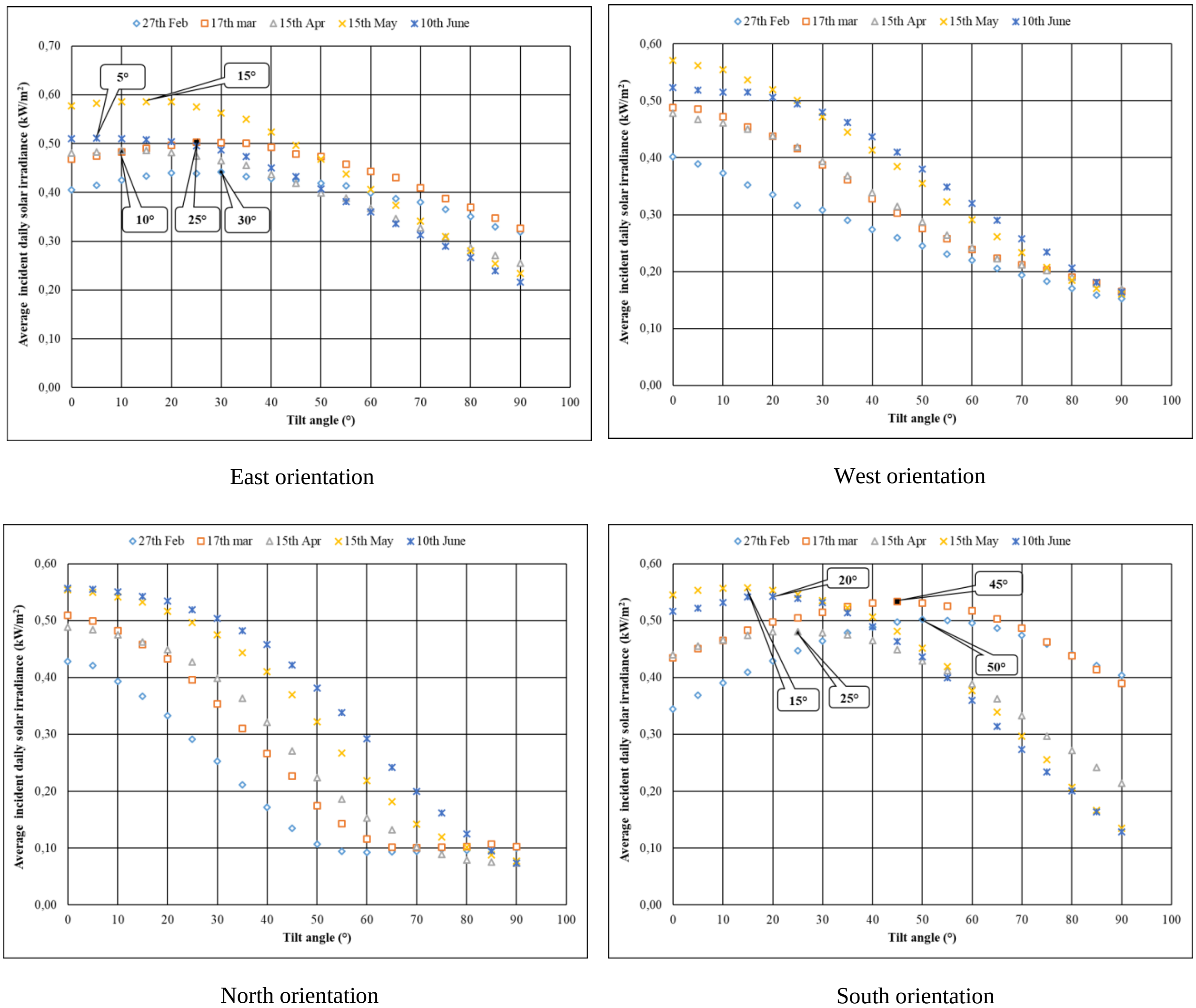


Figure 8. Effect of tilt angle on incident solar irradiance for the four main orientations (East, West, North, and South).

When the sun is high in the sky, nearly horizontal surfaces receive more solar energy than those slanted at various degrees (due to the angle at which solar radiation strikes these surfaces). The curve describing the evolution of incident solar irradiance vs. the tilt angle becomes more flattened when the sun is low in the sky compared to when it is high. Specifically, on February 27, the difference between the maximum and minimum energy received was approximately 38%. However, on May 15, this difference increased to over 90%.

Table 3 displays the outcomes of the Friedman test used to evaluate the effect of tilt angle on solar energy intercepted in the eastern direction. As can be seen, there is a significant difference in the solar irradiance gathered at different tilt angles since the P-values are lower than the significant probability ($p<0.05$), indicating that the inclination angle affects the amount of solar energy intercepted significantly.

When the sun is high in the sky, nearly horizontal surfaces receive more solar energy than those slanted at various degrees (due to the angle at which solar radiation strikes these surfaces). The curve describing the evolution of incident solar irradiance vs. the tilt angle becomes more flattened when the sun is low in the sky compared to when it is high. Specifically, on February 27, the difference between the maximum and minimum energy received was approximately 38%. However, on May 15, this difference increased to over 90%.

Table 3 displays the outcomes of the Friedman test used to evaluate the effect of tilt angle on solar energy intercepted in the eastern direction. As can be seen, there is a significant difference in the solar irradiance gathered at different tilt angles since the P-values are lower than the significant probability ($p<0.05$), indicating that the inclination angle affects the amount of solar energy intercepted significantly. It is important to note that there are no appreciable differences in the solar radiation incident on east-facing surfaces tilted at 0°, 5°, 10°, 15°, 20°, and 25° in April, May, and June, as revealed by the Friedman test; χ^2(5, N=50)=2.506, p=0.776, χ^2(5, N=46)=2.751, p=0.738, χ^2(5, N=45) =4.52, p=0.477, respectively. In other words, the incident solar irradiation in April, May, and June are not significantly affected by the inclination of the east-facing surfaces from 0° to 25° (a nearly horizontal surface).

When the solar exposed surface is oriented towards the west, the incident solar irradiance decreases as the tilt angle increases (Figure 8). Thus, the horizontal surface (β=0°) always receives maximum solar irradiation, while the vertical surface (β=90°) receives the least, regardless of the sun's position in the sky from February to June. In other words, from February to June, the best tilt angle for the west direction is 0° (horizontal surface). It is a fixed angle that does not change with the sun's path. The outcomes of the computations carried out by F. Jafarkazemi in Abu Dhabi (United Arab Emirates) (Jafarkazemi & Saadabadi, et al, 2013) are compatible with this result. Furthermore, throughout the study period, the difference between the maximum and minimum intercepted solar energy was significant, exceeding 160%.

Again, in case this result is applied to the construction sector in M'Sila, we can state that from February to June, terrace roofs (horizontal surfaces) get higher solar irradiance than roof surfaces oriented to the west or west-facing walls. Moreover, the west-facing walls are less irradiated than other inclined surfaces.

The results of the Friedman test, which aimed to assess the impact of tilt angle on solar energy intercepted in the western direction, are also shown in Table 3. As can be seen, there is a significant difference in the solar irradiance received at various tilt angles since the P-values are lower than the significance probability ($p<0.05$), showing that the inclination angle considerably impacts the amount of solar energy intercepted in the western direction.

Figure 8 demonstrates that nearly vertical surfaces facing west, with tilt angles of 75°, 80°, 85°, and 90° relative to the horizontal, receive approximately equal solar irradiance from April to June (a variation of less than 15% for each inclination). The P-values determined for each inclination are greater than the significance probability ($p>0.05$), which means that the Friedman test statistically supports this result: χ^2(2, N=43, 75°)=0.625, p=0.730, χ^2(2, N=43, 80°)=0.347, p=0.841, χ^2(2, N=43, 85°) =2.612, p=0.271, χ^2(2, N=43, 90°) =5.414, p=0.067.

When the solar exposed surface is oriented towards the north, the incident solar irradiance generally decreases with the tilt angle (Figure 8). Thus, regardless of where the sun is in the sky, the horizontal surface receives the maximum amount of solar radiation. In other words, for a north orientation, the optimal tilt angle, which receives the maximum amount of solar energy, is constant and does not change with the sun's annual trajectory (from February to June). The same result was found for the west orientation. It is worth noting that the incident solar irradiance does not decrease linearly as the tilt angle increases. When the sun is low in the sky, the incident solar irradiance decreases, passes through a minimum, and then increases very slightly (stabilizes) as the angle of inclination increases (February 27 and March 17 are examples of this). When the sun is high in the sky, such as on April 15, May 15, and June 10, vertical surfaces receive the least amount of solar energy (incident solar irradiance decreases with the tilt angle). Moreover, the difference between the maximum and minimum recorded incident solar irradiance is significant, topping 300% during the whole study period.

Once more, terrace roofs (horizontal surfaces) get higher solar irradiance from February to June than roof surfaces that are oriented to the north or north-facing walls. Moreover, compared to other north-inclination surfaces, the walls facing north receive less solar radiation.

Table 3 displays the outcomes of the Friedman test used to evaluate the impact of tilt angle on solar energy intercepted in the northern direction. As can be seen, there is a significant difference in the solar irradiance gathered at different tilt angles since the P-values are lower than the significance probability ($p<0.05$), indicating that the inclination angle affects the amount of solar energy intercepted significantly.

When the solar exposed surface is oriented towards the south, the incident solar irradiance rises as the tilt angle increases until it reaches maximum and then, decreases (the same trend as the east orientation). Moreover, when the sun is high in the sky, the vertical surface is the least radiated; this is the case on April 15, May 15, and June 10 (Figure 8). When the sun is low in the sky, as it is on February 27, the horizontal surface receives the least amount of solar irradiation (Figure 8). This result is evident because the sun rays fall parallel to the receiving surface.

As shown in Figure 8, the optimal tilt angle varies with the sun's annual path. Indeed, when the sun rises in the sky, the optimal tilt angle shifts to low slopes and when the sun moves down, the optimal tilt angle shifts to high slopes.

According to this research, walls facing south get less solar radiation from April to June than terrace roofs (horizontal surfaces) or roofs oriented in the same direction (incident solar irradiation difference exceeding 51%). In February, the sun is low in the sky; therefore, terrace roofs receive less solar radiation than south-facing walls. This finding can be extended to the winter, revealing that south-facing walls get more heat from the sun than terrace roofs do.

The findings of the Friedman test, which aimed to assess the effect of tilt angle on solar energy intercepted in the south, are likewise displayed in Table 3. As seen, the P-values are again lower than the significance probability ($p<0.05$), showing that the inclination angle considerably affects the amount of solar energy intercepted in the southern direction.

The amount of solar energy incident on a surface at any orientation and tilt varies with the sun's position in the sky. It depends on how the sun rays fall on the surface. The maximum radiation is received when the sun rays are perpendicular to the exposed surface. When the sun rays fall parallel to the surface, it receives the least amount of radiation. For example, a sloped surface facing south at 90° receives more solar radiation in February than in June (Figure 8). Additionally, as seen in Figure 8, the vertical surface receives more solar radiation in February than the horizontal surface. Moreover, the sun is lower in the sky in February than in June. Hence, the solar rays fall nearly perpendicular to the vertical surfaces and almost parallel to the horizontal ones in February. The opposite happens in June.

Table 3. Friedman test results for the effect of the tilt angle on the intercepted solar irradiance in all directions provided by SPSS 26.

	Orientations	Null hypothesis	Test	P value	Decision
Feb. 27	East West North South	The distributions of 0°, 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 50°, 55°, 60°, 65°, 70°, 75° , 80°, 85°, and 90° are the same.	Two-way analysis of variance by Friedman ranking for related samples	**0.000**	Rejection of null hypothesis
Mar. 17	East West North South	The distributions of 0°, 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 50°, 55°, 60°, 65°, 70°, 75° , 80°, 85°, and 90° are the same.	Two-way analysis of variance by Friedman ranking for related samples	**0.000**	Rejection of null hypothesis
Apr. 15	East West North South	The distributions of 0°, 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 50°, 55°, 60°, 65°, 70°, 75° , 80°, 85°, and 90° are the same.	Two-way analysis of variance by Friedman ranking for related samples	**0.000**	Rejection of null hypothesis
May 15	East West North South	The distributions of 0°, 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 50°, 55°, 60°, 65°, 70°, 75° , 80°, 85°, and 90° are the same.	Two-way analysis of variance by Friedman ranking for related samples	**0.000**	Rejection of null hypothesis
June10	East West North South	The distributions of 0°, 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 50°, 55°, 60°, 65°, 70°, 75° , 80°, 85°, and 90° are the same.	Two-way analysis of variance by Friedman ranking for related samples	**0.000**	Rejection of null hypothesis

As shown in Figure 7, the flat surface toward the north and the surface inclined at 30° south received maximum solar radiation during the study period from February to June.

In reality, this period is insufficient for determining the yearly optimal tilt angle, but it is sufficient to investigate the surface orientation and inclination effect on the solar energy captured.

5. CONCLUSIONS

This investigation, which aimed to study the effect of surface orientation and inclination on incident solar irradiation in M'Sila region from February to June, yielded the following results:

- The incident solar energy is greatly affected by the orientation and tilt of the solar-exposed surface as well as the position of the sun in the sky ($p<0.05$) since it depends on how the sun rays strike the surface;

- When the sun is low in the sky, the south orientation is most favored for an inclination greater than or equal to 25°. Furthermore, when the sun is high in the sky (as it is in April, May, and June), the east direction is preferred for inclination angles more than 75° and less than or equal to 90°. During the testing period, north-facing steeply sloped surfaces ($\beta \geq 55°$) received the least amount of solar irradiation.

- For east and south orientations, incident solar irradiance rises as a function of tilt angle, reaching maximum (optimal angle) and then decreasing. Generally, the incident solar irradiance decreases as the tilt angle increases for west and north orientations. Moreover, for east and south orientations, the ideal tilt angle varies with the sun's annual path, whereas it is constant at 0° for west and north orientations.

- The flat surface toward the north and the surface inclined at 30° south receive maximum solar radiation during the study period from February to June.

- The results make it possible to identify the orientations (North, South, East, and West) and inclinations (terrace roofs, roof, and vertical walls) in the building sector that are the most suited for solar heat input, provided by the sun both in summer and winter. Indeed, east-facing walls receive more solar energy when the sun is high in the sky than in other orientations. However, when the sun is low in the sky, south-facing walls are exposed to more solar radiation than other orientations. Moreover, the north-facing walls are the coldest part of the building envelope since they receive the least amount of solar radiation. East, west, and north facing walls do not receive as much solar radiation as terrace roofs. During the summer, terrace roofs are exposed to more solar radiation than south-facing walls. The inverse is true in the winter.

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NOMENCLATURE

df	Degrees of freedom
N	Sampling number
P	Probability value
Greek letters	
α	Significance probability
β	Inclination angle [°]
γ	Surface azimuth angle [°]
χ^2	Chi square

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