Meteorological Variability and Use of Solar Energy in the Mantaro Valley, Peru

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Abstract- Innovation of technologies that use solar energy as a source of energy, requires the meteorological parameters of the place where they will be put into operation. Existing publications on meteorological parameters are general, presented for reporting, but not for use with a source of information to design technologies that will use the sun as an energy source. This article is intended to describe variations in meteorological parameters such as solar radiation, ambient temperature, relative humidity, and wind speed in the Mantaro Valley, to be applied in the design of technologies that use solar energy, the annual averages obtained are 394 W/m2, 14.3°C, 61% and 2.7 m/s, respectively.

Keywords Renewable energy, solar irradiance, temperature, relative humidity, solar technology.

1. Introduction

The measurement of solar radiation and meteorological parameters have a wide range of applications such as engineering, agriculture, architecture, electricity generation, design and operation of solar technologies, construction of climate predictions models, as well as applications to health, food and human activities [1]–[5].

The potential of solar energy reaching the Earth´s surface is not adequately exploited, despite the existence of technology needs to add value to the products of the residential and industrial sector of the Mantaro Valley in Perú.

One of the causes is the lack of real information, versus simulations that generally move away from reality with discouraging data. The design of a system that uses renewable energy must be robust to the unknown climatic conditions that it will encounter during its lifetime, for which it is crucial to use an appropriate set of real meteorological data during its design phase [6].

The solar energy application in the residential sector is in the design of heating, air conditioning, cooling, and lighting systems. Besides, the effects of climate change on meteorological parameters are generating significant changes in the design and energy-saving operation of heating, ventilation, and air conditioner systems. In the design of buildings, they focus on systems that provide thermal comfort to people during climatic variations. The thermal sensation is the way a person feels in a thermal environment, whose basic parameters are related to air temperature, humidity, wind speed, solar radiation, human activity, and clothing [7].

Solar radiation and wind speed have an effect on thermal sensation which is dependent on-air temperature. When the air temperature is 25°C, every half meter per second increase in wind speed could compensate for the discomfort of at least 10°C excess [8]. For instance, in various cities of China were observed a decrease in design load in winter, while in summer an increase, so design strategies should be applied following the different characteristics of climate change of each location [9]. In photovoltaic systems, meteorological parameters influence in their accommodation, which is determined by wind speed and wind direction, ambient temperature, and solar radiation [10], [11], [12]. In a solar pumping system, the fluctuation of the photovoltaic energy may affect the performance of the water pumping system which will depend on the solar irradiation and the ambient temperature [13].

On the other hand, the applications of solar energy in the industrial sector, where hot air, water vapor, cooling is applied, also depend on the availability of solar energy and the behavior of environmental parameters [14], [15]. Solar drying uses hot air for the preservation and processing of crops, dairy, wood, biomass, wastewater, textiles, bricks, among others [16]. In solar drying of wastewater sludge, a dry solids concentration of 80% is reached, where the wind speed had a greater effect than the temperature [17]. In sewage landfills, barometric pressure, ambient temperature, wind speed, and solar radiation influence on CH_4 emissions, regulating both barometric pressure and wind speed could result in lower CH_4 emissions from landfills to decrease their contribution to global warming [18]. The combination of solar energy and desalination technologies has also been applied, as a means of solving the potable water scarcity problem of various parts of the world [6], [19].

Weather factors also influence the wind and solar plants. Efficiency of wind farms is highly dependent on the climatic factors [20]. The solar plant is modeled and analyzed using parabolic trough and Linear Fresnel collectors at different operation modes in typical winter and summer days, to concentrate the solar radiation [21].

Therefore, this work aimed provides information on variations in meteorological variables such as solar radiation, ambient temperature, relative humidity, and wind speed in the Mantaro Valley to be applied in the design of systems that provide thermal comfort and photovoltaic energy in the residential sector, and in the preservation and processing of agricultural products, wastewater, and others that require clean energy, in the industrial sector.

2. Methodology

Our methodology focuses in provide information on meteorological parameters: solar radiation (W/m^2), relative humidity (%), ambient temperature (°C), and wind speed (m s-1) for solar energy applications. The measurements of these parameters were carried out at the actinometric and meteorological monitoring stations (installed 45 m above ground level) belonging to the Laboratory of Renewable Energy from the Universidad Nacional del Centro del Perú, which is in the Mantaro Valle (MV). The MV is situated to the south-central highlands of the Andes of Peru, with an elevation of about 3330 m above sea level and covered an extension of 53 km long and a width that fluctuates between 4 km and 21 km [22].

Table 1. Location of the actinometric and meteorological stations

GMT	-5
Latitude	12.0313669° S
Longitude	75.2352870° W

The location of the actinometric and meteorological stations makes it possible to consider that the data obtained is valid for the entire Mantaro Valley (Figure 1).

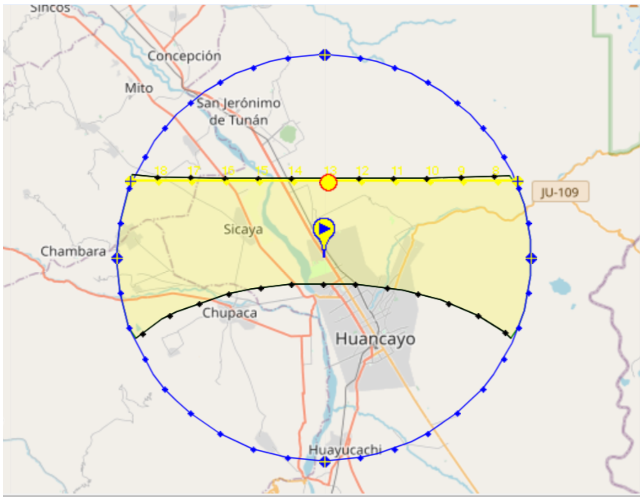

Fig. 1. Location of the actinometric and meteorological station (Prepared with SunEarthTools [23])

The Mantaro Valley is a privileged place for the development of technologies that use solar radiation as an energy source because it receives annual global irradiation greater than 2300 Wh/m^2 (Figure 1).

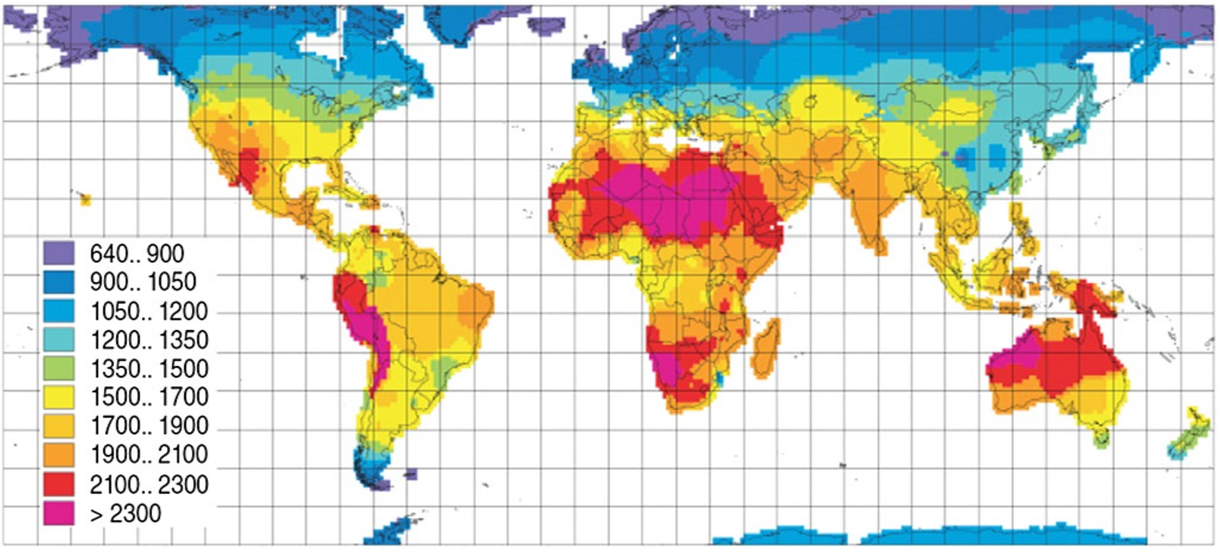

Fig. 2. Total global annual solar irradiation in Wh/m2, [24].

Table 2. Technical specifications of the measuring instruments

Instrument	Model	Principio	Rank	Accuracy
Pyranometer	Kipp & Zonen CMP21	Thermodetector	0 - 4000 W/m²	< 1 %
Thermometer	WS501-UMB	NTC	-50 - 60 °C	±0,2 °C
Hygrometer	WS501-UMB	Capacitive	0 - 100% h.r.	±2% h.r.
Anemometer	WS501-UMB	ultrasonic	0 - 75 m/s	±0,3 m/s

Measurements of wind speed (m/s), ambient temperature (°C), solar radiation (W/m2), and relative humidity (%) were carried out from January 2018 to December 2019 using the WS501-UMB automated meteorological system. Data were registered at each minute. Specifications and characteristic of all instruments are presented in Table 2.

The data were processed using MS Excel pivot tables. The elevation angle and solar polar diagram plots of the Mantaro Valley were performed with SunEarth Tools software [23]. The results of solar radiation and ambient temperature are presented as a daily average for one year and as an annual-minute average for one day. The results of the rest of the meteorological parameters are presented as an average per day for one year.

3. Results and discussion

The results are presented as actinometric and meteorological characteristics. In actinometric characteristics, the elevation angles and the azimuth at solar noon, the solar polar diagram, the variation of the annual global irradiance, and the variation of the daily global irradiance are presented.

In the meteorological characteristics are presented the maximum and minimum variations of the ambient temperature of a year, the maximum, minimum, and average variations of the temperature of an annual day, the average of the variations of the relative humidity during the year and the average of the variations of the wind speed during the year.

3.1. Actinometric characteristics

For the designs of technologies that use solar irradiation as a source of energy, it is important to determine the time of noon, which is when the highest solar irradiance is obtained. Likewise, the elevation angles and azimuth will allow us to define the angles of the collectors and the variations that it will have during the year (Table 3). Thus, determine the orientation, inclination angle, elevation angles, and azimuth have a crucial effect on solar technology [25], [26].

From Figure 3, it's observed that in the Mantaro Valley, the sun showed its lowest elevation angle (54.5°) on June 21st and posteriorly reached 90° and 101.4° degrees (78.6° from the south) on December 21th, returning to the initial position in the following six months. The orientation of the long and short solar collectors is different and their orientation must allow the annual performance, which must be based on the months of maximum solar irradiation [27].

Table 3. Elevation angles and azimuth at solar noon

Date	Noon	Elevation	Azimuth
21/03/2019	13:07	77.5°	0°
21/06/2019	13:03	54.5°	0°
21/09/2019	12:54	77.5°	0°
21/12/2019	12:59	78.6°	180°

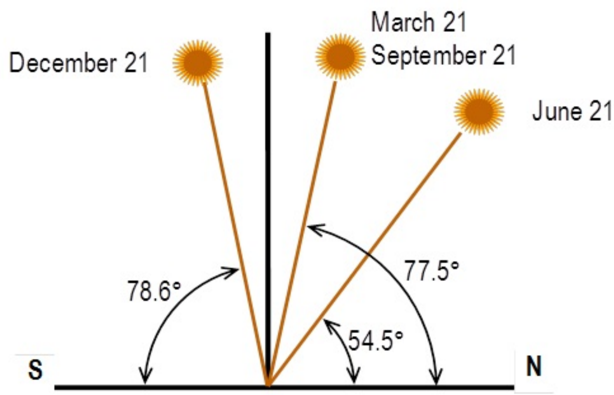

Fig. 3. Solstice and equinox elevation angles in the Mantaro Valley

The solar polar diagram (Figure 4) is the stereographic projection of the sun´s journey during the day of the different months of the year, being June 21 shortest day of the year with a duration of 11:25:10 (HH:MM: SS), while December 21st the largest reaching a maximum duration of 12:50:10 (HH:MM: SS). Both complete a cycle.

The global solar irradiance in the Mantaro Valley (Figure 5) corresponds to the daily average of the measurements carried out during the time of the study, with a daily average of 394 W/m2. The cloudiness of January, February, March, and part of April affect the transfer of solar irradiance through the atmosphere. From May, this cloudiness goes down to have the sky completely clear arriving in June and July, but in August to October, the irradiance remains constant, while that in November and December is increased.

The solar irradiance of the surface is affected by the type of clouds, its high spatial and temporal variability, its speed and position relative to the sun [28].

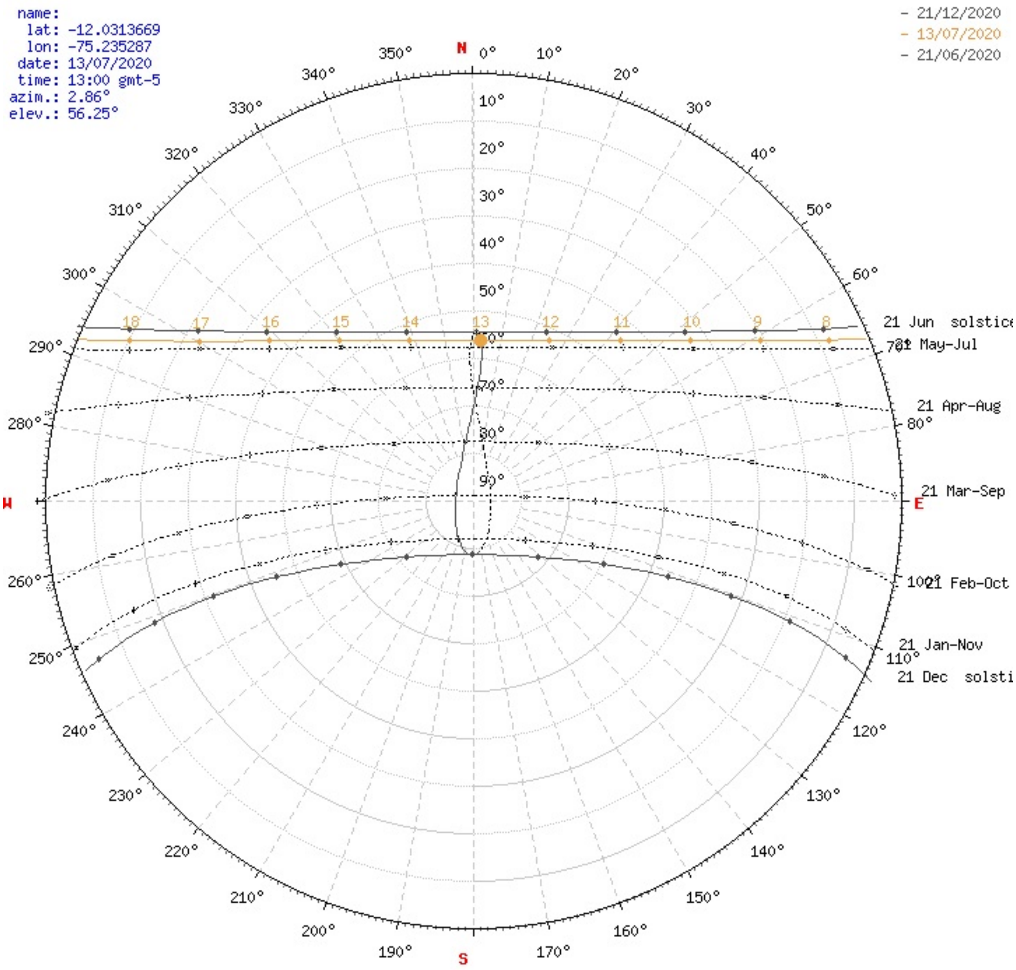

Fig. 4. Solar polar diagram for the Mantaro Valley (prepared with SunEarthTools [23])

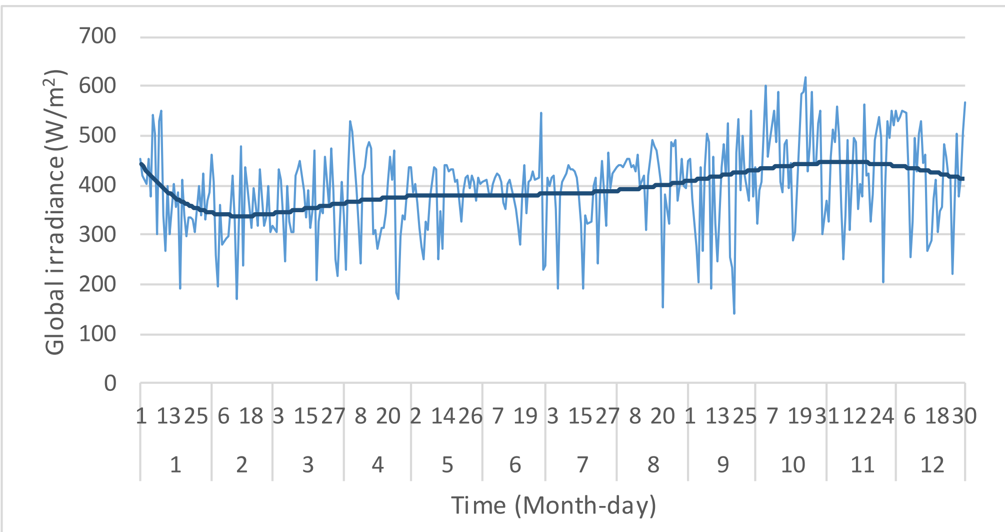

Fig. 5. Variation in annual global irradiance

The global irradiance in Figure 5 represents the average of the measurements made during the years 2018 and 2019. The maximum global irradiance, in the measurement period, was November 7, 2018, date when 1562 W/m^2 was reached. Minute-by-minute measurements (Figure 6) show variations in irradiance up to 800 W/m^2, due to environmental factors, mainly the presence of clouds. Local cloud coverage or atmospheric phenomena present at different times and locations could influence irradiance by generating instantaneous changes up to 600 w/m^2 [29].

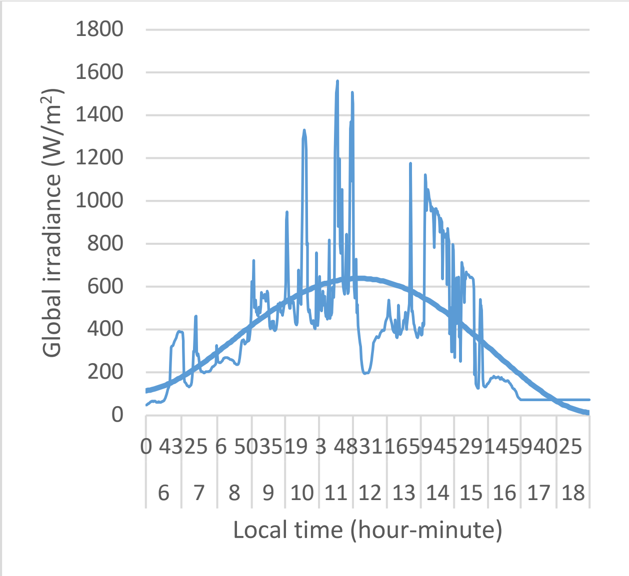

Fig. 6. Variation of global irradiance on November 7, 2018

Comparing the global irradiance of the day of maximum solar radiation and the average global irradiance of the annual day (Figure 6 and Figure 7), it is observed that the area under the curve of the last one is greater than that of the first, indicating more energy.

It means that, even with maximum radiation in the day, the annual average is higher because there are other days when there is no interference from environmental factors.

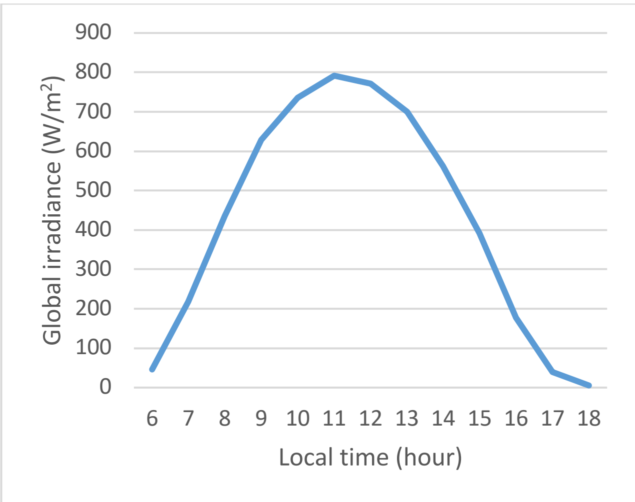

Fig. 7. Variation of the global irradiance, annual day average

For the design of solar technologies, it is interesting to know the amount of energy that can be harnessed from solar radiation.

The average annual irradiance day is 424 W/m^2, considering the number of hours of sunshine that varies between eleven and thirteen hours, the amount of energy used usable each day can be determined. The average annual day irradiance data are shown in Table 4.

In the Mantaro Valley, the angle of elevation of the sun varies from 54.5° to 101.4° between 21st June to 21st December, with an azimuth angle of 0°. The overall total average irradiance is 394 W/m^2 and the annual-day average is 424 W/m^2, having reached the maximum irradiance of 1562 W/m^2 in November.

Table 4. Global irradiance, the average annual day

Hour of the day	Average of Global Irradiance (W/m^2)
6	46.03
7	218.15
8	435.72
9	628.54
10	735.79
11	791.66
12	771.84
13	699.94
14	561.58
15	391.26
16	177.51
17	39.60
18	5.37

3.2. Meteorological characteristics

The meteorological parameters that have a direct impact on the design of solar technologies for the residential and industrial sectors are the ambient temperature, relative air humidity, and wind speed.

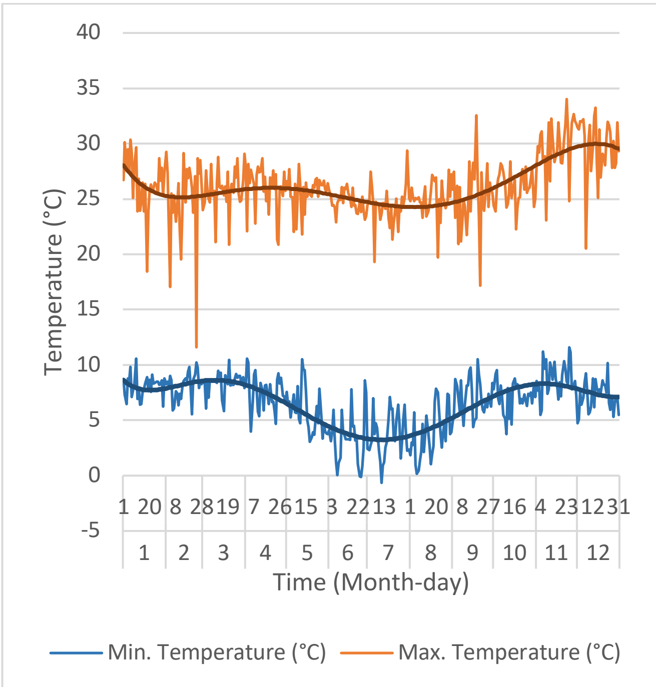

Fig. 8. Variation of maximum and minimum temperature

The variation of the environmental temperature in the Mantaro Valley reached a maximum of 34 °C in November, and the minimum of -0.6°C in July, with an annual average of 14.3°C within the period of study (Figure 8). This variation influences the design of air conditioning systems, photovoltaic systems, and industrial application technologies. The assessment of environmental meteorological parameters is necessary when designing a building with good efficiency air conditioning since the continuous climate change varies such parameters between summer and winter [9]. Obtaining maximum available photovoltaic energy is related to solar radiation and photovoltaic panel temperature, variations in ambient temperature affect the operation of the photovoltaic panel when it exceeds the nominal operating temperature [10].

Ambient temperature and relative air humidity have a very important influence on solar drying, specifically because of the temperature and hygrometric characteristics of the air mass [30].

The temperature of a day on the Mantaro Valley can range from some degrees to about 20 20°C. Usually, the minimum temperature of the day is recorded around six o´clock in the morning, then increased until reaching the maximum temperature around noon, then start the descent (Figure 9). An important factor in the design of solar heating, air conditioning, and drying technologies is the variation of the temperature during the 24 hours of the day.

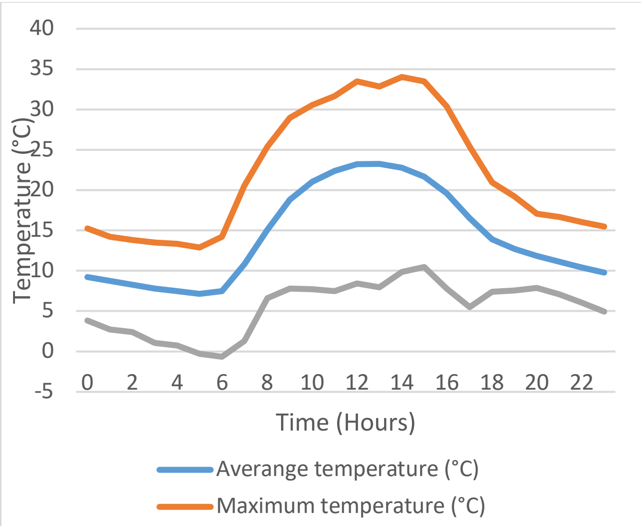

Fig. 9. Variation temperature in a day-annual

The operation of solar heating is more requested during the winter months and air conditioning is required during the summer months, the first requires energy at night and the second in the day. The variation in the ambient temperature of a day is mainly used to calculate the maximum design load of the cooling equipment [9]. In solar dryers, one of the most important parameters is air temperature, this varies the efficiency and efficiency of the collector [31]. Solar radiation and ambient temperature affect the air temperature inside the drying chamber because it is extracted from the ambient air [32].

The average annual relative humidity in the Mantaro Valley is 61%. During the investigation, the maximum relative humidity reached was 100% in March, and the minimum of 6% in July; therefore, the recommended dates for solar drying are June, July, and August.

In the solar drying process, the relative humidity of the air, its hydrometric characteristics, and the ambient temperature are variables that have a lot of influence [30]. The relative humidity is inversely proportional to temperature, thus, to higher temperatures, minor humidity in the drying chamber. Besides, when the temperature decreases, the relative humidity of the drying chamber will become equal to the relative humidity of the environment [32].

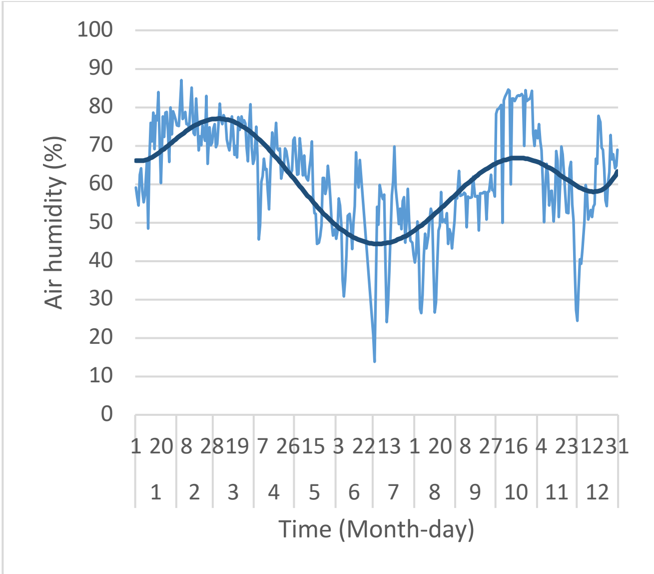

Fig. 10. Variation of relative air humidity

The annual average wind speed is 2.7 m/s; with extreme variations of 0 m/s to 24 m/s presented in December. Wind speed influences the thermal comfort of heating and air conditioning systems, in the efficiency of photovoltaic systems, and mainly in wind power generation systems. Wind speed could compensate for the negative effect of solar radiation on thermal comfort, but its effect decreases when the air temperature is greater than 31 °C [8]. In photovoltaic systems, heat loss through convection is determined by the direction and speed of the wind, which influences their efficiency [10].

Wind speed directly influences the development of wind energy projects; if the wind speed is close to the cutting speed of the turbine it harms the gearbox due to stops; affecting the safety, stability, and reliability of the electrical power system [33]. Wind speed variability influences the energy production of a wind farm, so it is proposed to integrate multiple wind farms to reduce the fluctuation in total energy production [34].

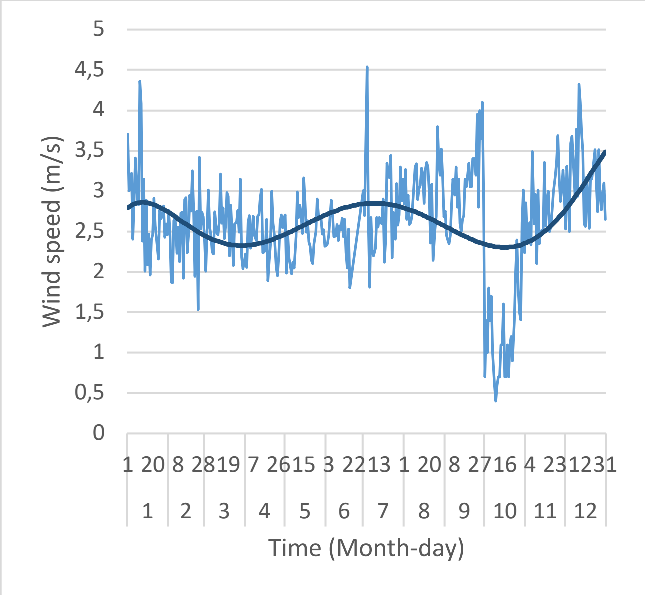

Fig. 11. Variation in wind speed

Then, the meteorological parameters that have a direct impact on the design of technologies for the industrialization of agricultural production are environmental temperature, relative humidity, and wind speed. The average annual temperature in the Mantaro Valley was 14.3°C, reaching a maximum temperature of 34°C in November and a minimum temperature of -0.6°C in July. The average annual relative humidity is 61%, with a maximum of 100% reached in March and a minimum of 6% reached and July. The average annual wind speed was 2.7 m/s.

4. Conclusions

The Mantaro Valley is a privileged place for the development of technologies that use solar radiation as an energy source, since it has solar energy of approximately 5 kWh/m2, with an overall total average global irradiance of 394 W/m2, and average annual day of 424 W/m2. Likewise, the sun moves with an angle of elevation of 54.5° degrees from June until reaching an angle of elevation of 101.4° in December, concerning the north.

Among the meteorological parameters studied are the temperature, with an annual average of 14.3°C, reaching a maximum temperature of 34°C in November and a minimum temperature of -0.6°C in July. The relative humidity, with an annual average of 61%, reaching 100% in March and a minimum of 6% in July; with an annual average wind speed of 2.7 m/s.

The configuration of solar technologies must consider these results as restrictions or calculation data. Solar irradiance will be used to determine the input energy to the system and to make autonomy or support decisions. The low temperatures will be restrictions to overcome through insulation or thermal storage.

Finally, the study of the variation of solar radiation and meteorological parameters are of great importance for the optimal exploitation of solar energy through the design of technologies for residential and industrial applications. It allows using of free energy from the sun of approximately 5kWh/m^2, with high solar irradiance in the months with lower temperatures, suitable for application in solar drying, solar heating, and solar cooling systems.

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