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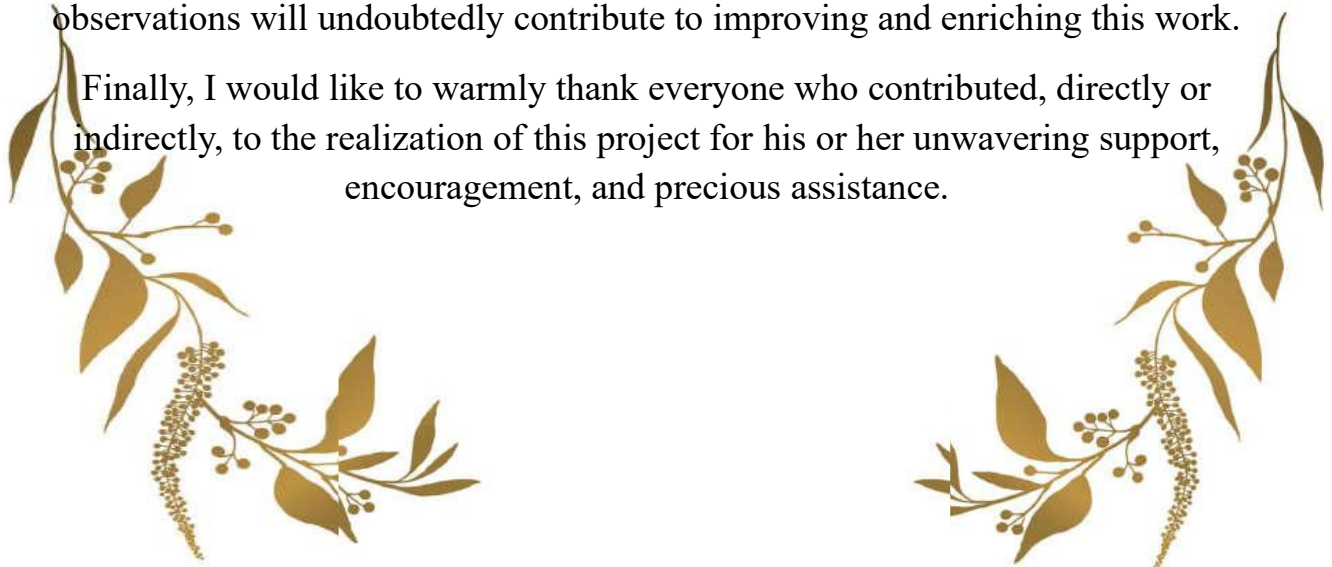
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DEDICATION

With profound gratitude and sincere appreciation, I'm honored to dedicate this humble work to my beloved parents, whose endless love, unwavering support, and countless sacrifices have been the foundation of my academic journey.

Throughout my academic journey, they have always stood by my side, encouraging me with patience, wisdom, and prayers that illuminated my path and strengthened my determination to overcome every challenge.

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DEDICATION

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Table of Contents

<i>REMERCIEMENTS</i>	0
<i>DEDICATION</i>	0
<i>DEDICATION</i>	0
Chapter I : Solar Resource	0
I.1 Introduction	1
I.2 Solar energy	1
I.3 Importance of solar radiation	1
I.3.1 Heat production	1
I.3.2 Heat generation	1
I.4 Solar energy system	1
I.4.1 Solar photovoltaic energy	2
I.4.1.1 Operation	2
I.4.2 Solar thermal energy	3
I.4.2.1 Operation	3
I.5 Domestic hot water (DHW)	3
I.6 Renewable energy in the world	4
I.7 Advantages of renewable energy	6
I.8 Reduction of CO₂ emissions	7
I.9 The solar energy source	7
I.9.1 The sun	7
I.9.2 Solar radiation and sources	7
I.9.2.1 Illuminance	8
I.9.2.2 Irradiation	8
I.9.3 Solar radiation available on earth	9
I.9.3.1 Direct solar radiation	10
I.9.3.2 Diffuse solar radiation	10
I.9.3.3 Global solar radiation	10
I.10 Solar radiation in algeria	10
I.11 Earth and sun motion	12
I.11.1 Geographic coordinates	13

I.11.1.1 Latitude (Φ).....	13
I.11.1.2 Longitude (L°).....	13
I.11.1.3 Altitude (z)	13
I.11.1.4 Meridian	13
I.11.2 Hourly celestial coordinates	14
I.11.2.1 Solar declination (d)	14
I.11.2.2 Hour angle (ω)	14
I.11.3 Horizontal celestial coordinates	14
I.11.3.2 Solar azimuth (a).....	15
I.11.3.3 Angle zenithal (Θ_z).....	15
I.12 Apparent trajectory of the sun.....	16
I.13 Emission from bodies	16
I.13.1 Emission from a Black Body.....	16
I.13.2 Emission from a Real Body.....	17
I.14 Solar fraction.....	17
I.15 Solar energy collection.....	18
I.15.1 Solar thermodynamic energy.....	19
I.15.2 Solar photovoltaic energy.....	19
I.15.3 Solar thermal energy	19
I.15.3.1 Solar thermal system.....	19
I.15.3.2 Heat transfer modes in solar collectors	19
I.16 Conclusion	21
Chapter II: Solar Heating System	29
II.1 Introduction.....	23
II.2 Presentation of system studied	23
II.2.1 Description general of system of water heater solar	23
II.2.2 Importance and application of system	24
II.2.2.1 System solar combined (SSC)	24
II.2.2.2 Heating pool.....	25
II.3 Principle of functioning of the components.....	25
II.3.1 Sensors solar	25
II.3.1.1 Principle of functioning	25
II.3.1.2 The types of different sensors.....	26

II.3.1.3 The components of a sensor solar thermal plan.....	28
II.3.2 Reservoir of storage	31
II.3.2.1 Materials that are resistant	31
II.3.2.2 The insulation.....	32
II.3.2.3 Heat exchanger thermal	32
II.3.2.4 The supplement.....	32
II.3.2.5 Stratification In the ball of storage	32
II.3.3 Hydraulic circuit	34
II.3.3.1 The conduits.....	34
II.3.3.3 Valve stop	34
II.3.3.4 Valve of security and the manometer	34
II.3.3.5 Vase operating.....	35
II.3.3.6 Flap backflow.....	35
II.3.3.7 flow meter	35
II.3.3.8 thermometer	36
He measures the temperature of THE fluid entrance and exit in THE sensor.	36
II.3.3.9 Circulator.....	36
II.3.4 Regulation and orders	38
II.3.4.1 Thermostat.....	38
II.3.4.2 Resistance electric.....	39
II.3.4.3 Controller.....	39
II.4 Facility of a water heater solar	40
Chapter III: System Sizing.....	41
III.1 Introduction	43
III.2 Geographic localisations (Wilaya de Laghouat)	43
III.3 Climatic Characteristics	44
III.4 Laghouat Climate Data	44
III.4.1 Temperatures	45
III.4.2 Sunlight	46
III.4.2.1 Solar Radiation Distribution	47
III.4.2.2 Photoperiod and Sunshine Duration	47
III.4.3 Thermal Resistance of Exterior Wall	49
III.4.3.1 Formula.....	49

Chapter IV: Simulation with TRNSYS	55
IV.1 Introduction.....	56
IV.2 Simulation with TRNSYS	56
IV.2.1 Introduction to the TRNSYS software	56
IV.2.2 TRNSYS environment	57
IV.2.3 TRNSYS tools	57
IV.2.4 Applications	58
IV.2.5 Definition of Outputs	58
IV.3 Modelling and simulation.....	59
IV.3.2 Presentation of the installation model.....	60
IV.3.2.2 Added components and configuration.....	61
IV.4 Conclusion.....	63
Chapter V: Results and Interpretation	77
V.1. Introduction	65
V.2. Meteonorm data.....	65
V.3. Calculation of heating and domestic hot water requirements	68
V.3.1. Verification and reference heat losses	68
V.3.2. Calculation of heating capacity	69
V.3.3. The system's collector area and meeting requirements	69
V.3.4. Corrected calculation page	70
V.5 Estimation of the Building Energy Needs	76
V.6 Conclusion	77
General Conclusion.....	79
References and Bibliographies.....	81

List of shapes

Figure I. 1: shows the solar system.....	2
Figure I. 2: Photovoltaic cell diagram.....	2
Figure I. 3: thermal sensing apparatus illustration.....	3
Figure I. 4: Schematic Diagram of a Solar Water Heater.....	4
Figure I. 5: Predicted distribution of primary energy demand by energy source	5
Solar water heaters are continuously developing and are widely used across different fields, such as swimming pool heating and residential space heating. <i>Figure I. 6</i> above presents the solar water heater market distribution by region and across various sectors.	5
Figure I. 6: Solar Water Heater Market — Growth Rate by Region.....	5
Figure I. 7: The Amount of Irradiation Reaching the Earth's Surface Is Affected by the Medium It Passes Through.....	8
Figure I. 8: World Map of Average Annual Solar Irradiation in kWh/m ² /day on a Horizontal Plane.....	9
Figure I. 9: The Three Types of Solar Radiation	9
Figure I. 10: Components of Solar Radiation.....	10
Figure I. 11: Solar Irradiation Map of Algeria.....	11
Figure I. 12: The Sun's Position at a Site Varies According to the Earth's Rotation and Revolution Around the Sun.	12
Figure I. 13: Celestial Sphere	12
Figure I. 14: Geographic Coordinates	13
Figure I. 15 : Hour Angle Coordinates	14
Figure I. 16: Coordinates That are horizontal.....	15
Figure I. 17: Apparent Motion of the Sun	16
Figure I. 18: Schematic of Solar Energy Capture.....	18
Figure II. 1: plan of a water heater solar	24
Figure II. 2: plan se system solar combined	25
Figure II. 3: plan of a sensor plan.....	26
Figure II. 4 : The sensor solar No glazed	27
Figure II. 5: tubes under a vacuum installed in a roof.....	28
Figure II. 6: components of a sensor solar.	28
Figure II. 7: ball of stratification SOLUS.....	33
Figure II. 8: insulation of the conduits	34
Figure II. 9: a valve stops	34
Figure II. 10: valve of safety with a pressure gauge.....	35
Figure II. 11: vase operating.....	35
Figure II. 12: check valve.....	35
Figure II. 13: thermometer	36

Figure II. 14: A circulator of liquid	36
Figure II. 15 : one piece.....	37
Figure II. 16: diagram of water heater separated thermophili son.....	37
Figure II. 17: diagram of water heater traffic strength	38
Figure II. 18: regulator	39
Figure II. 19: plan present the components installation water heater solar	40
Figure III. 1: Climatic Characteristics.....	44
Figure III. 2: Daily temperature	45
Figure III. 3: Average monthly temperatures	45
Figure III. 4: Monthly solar irradiation	46
Figure III. 5: Duration of insolation.	46
Figure III. 6: Site plan of the prototype house.	47
Figure IV. 1: TRNSYS operational diagram	57
Figure IV. 2: Definition of outputs.....	58
Figure IV. 3: Meteonorm software interface	59
Figure IV. 4: Modelling using TRNSYS software	60
Figure IV. 5: Control cards and Type 109 (Weather data reader / processor).....	62
Figure V. 1: Monthly global and diffuse solar radiation in Laghouat (Meteonorm figure provided by the user).....	66
Figure V. 2: Monthly temperature distribution in Laghouat (Meteonorm figure provided by the user).	67
Figure V. 3: Evolution of daily maximum and minimum temperatures in Laghouat (Meteonorm figure provided by the user).	68
Figure V. 4: Overall TRNSYS response showing ambient temperature, control-related variable, collector behavior, and result/output over the simulated period.	73
Figure V. 5: Periodic evolution of the control-related variable labelled “appoint.”	74
Figure V. 6: Ambient temperature evolution over a selected simulation interval	74
Figure V. 7: Collector thermal behavior showing repeated operating peaks during active solar periods.....	75
Figure V. 8: Step-like output/result signal associated with controlled system operation.	76

Nomenclature of Symbols

1.

Solar Geometry and Astronomical Parameters

- ω : Hour angle [deg]
- TSV: True Solar Time [h]
- h : Solar altitude angle [deg]
- a : Solar azimuth angle [deg]
- θ_z : Solar zenith angle [deg]
- d : Solar declination angle [deg]
- L : Latitude [deg]

2. Radiation and Thermal Emission

- M_0 : Total emissive power of a black body per unit area [W/m^2]
- M : Emissive power of a real body per unit area [W/m^2]
- σ : Stefan-Boltzmann constant [$\text{W}/\text{m}^2 \cdot \text{K}^4$]
- ϵ : Emissivity of a surface [-]
- T : Absolute temperature [K]
- λ : Wavelength [μm]

3. Solar Fraction

- FS: Solar fraction [-]
- Q_{solar} : Useful thermal energy supplied by the solar system [J or kWh]
- Q_{total} : Total thermal energy demand [J or kWh]

4. Heat Transfer Parameters

- Φ : Heat flow rate / thermal power [W]
- λ : Thermal conductivity [$\text{W}/\text{m} \cdot \text{K}$]
- S : Heat transfer surface area [m^2]
- $\text{grad}T$: Temperature gradient [K/m]
- h : Convective heat transfer coefficient [$\text{W}/\text{m}^2 \cdot \text{K}$]
- T_p : Surface temperature [$^{\circ}\text{C}$ or K]
- T_f : Fluid temperature [$^{\circ}\text{C}$ or K]

5. Solar Collector Performance

- ΔT : Temperature difference [$^{\circ}\text{C}$ or K]
- T_m : Mean fluid temperature [$^{\circ}\text{C}$]
- T_a : Ambient temperature [$^{\circ}\text{C}$]
- Q_{inci} : Incident solar energy on the collector [W or J]
- A : Collector area [m^2]
- G : Solar irradiance [W/m^2]
- Q_{abs} : Absorbed solar energy [W or J]
- α : Absorptivity of the collector surface [-]
- Q_{perte} : Thermal heat loss from the collector [W or J]
- K : Overall heat loss coefficient [$\text{W}/\text{m}^2 \cdot \text{K}$]
- T_c : Collector temperature [$^{\circ}\text{C}$]
- Q_{utile} : Useful thermal energy gained by the collector [W or J]
- $\dot{m}$: Mass flow rate of the heat transfer fluid [kg/s]
- C_p : Specific heat capacity of the fluid [$\text{J}/\text{kg} \cdot \text{K}$]
- T_{fe} : Fluid inlet temperature [$^{\circ}\text{C}$]
- T_{fs} : Fluid outlet temperature [$^{\circ}\text{C}$]

- η : Collector efficiency [%]

6. Thermal Storage

- **Q**: Stored or transferred heat energy [J or W]
- **m**: Mass of water or storage fluid [kg]
- **cp**: Specific heat capacity [J/kg·K]
- **ΔT** : Temperature rise or temperature variation [°C or K]

7. Building Heat Loss and Thermal Sizing

- **D**: Total heat loss coefficient [W/°C]
- **DT**: Transmission heat losses [W/°C]
- **DR**: Ventilation or air renewal heat losses [W/°C]
- **Ds**: Surface heat losses [W/°C]
- **Dli**: Linear thermal bridge losses [W/°C]
- **Dsol**: Floor heat losses [W/°C]
- **Dlnc**: Heat losses toward unheated adjacent spaces [W/°C]
- **U**: Overall heat transfer coefficient (thermal transmittance) [W/m²·K]
- **R**: Thermal resistance [m²·K/W]
- **S**: Surface area [m²]
- **ΔT** : Indoor-outdoor temperature difference [°C]

8. Domestic Hot Water (DHW)

- **QESC**: Energy required for domestic hot water production [J/h or W]
- **QESC_Watts**: Domestic hot water energy converted into watts [W]
- **4200**: Specific heat capacity of water [J/kg·K]
- **(50 – 10)**: Water temperature rise [°C]

9. Solar Collector Sizing

- **Sca**: Required solar collector area [m²]
- **PSU**: Annual useful solar productivity per unit collector area [kWh/m²]

10. Additional Thermal Parameters

- **Rsi**: Internal surface thermal resistance [m²·K/W]
- **Rse**: External surface thermal resistance [m²·K/W]
- **Km**: Thermal transmittance of the wall [W/m²·K]
- **Kpo**: Thermal transmittance of the window [W/m²·K]
- **Kf**: Thermal transmittance of the door [W/m²·K]
- **Dréf**: Reference heat loss coefficient required by regulation [W/°C]

Chapter I : Solar Resource

I.1 Introduction

Solar energy is one of the most abundant and accessible renewable energy sources. Algeria, located in North Africa, benefits from a high level of solar irradiance throughout the year, making it highly suitable for solar energy exploitation. Harnessing solar energy not only reduces reliance on fossil fuels but also contributes to environmental protection and energy security.

The aim of this chapter is to analyze the solar potential in Algeria, including its geographical distribution, seasonal variations, and relevant meteorological parameters.

I.2 Solar energy

Solar energy comes from the sun's radiation and is a type of renewable energy. The sun sends a lot of radiated energy to the solar system, but only Earth catches a small part of it. Most solar energy has direct uses like drying, heating, and agriculture. Even though this energy gets weaker as it passes through the atmosphere, a good amount still reaches the surface. Places with moderate climates can see about 1000 w/m^2 , and areas with cleaner air can get up to 1400 w/m^2 .

I.3 Importance of solar radiation

Solar radiation is important for the progress and performance of renewable energy sources, like photovoltaic and solar thermal energy.

I.3.1 Heat production

Photovoltaic solar panels use semiconductor cells to convert sunlight into electricity. The intensity and duration of solar exposure greatly influence the proper functioning of this process.

I.3.2 Heat generation

Collectors in solar thermal systems absorb solar heat and transfer it to a fluid. This heat can then warm water or buildings, or it can create steam in power plants.

I.4 Solar energy system

The above figure presents two different solar energy systems designed to produce electrical energy and heat.

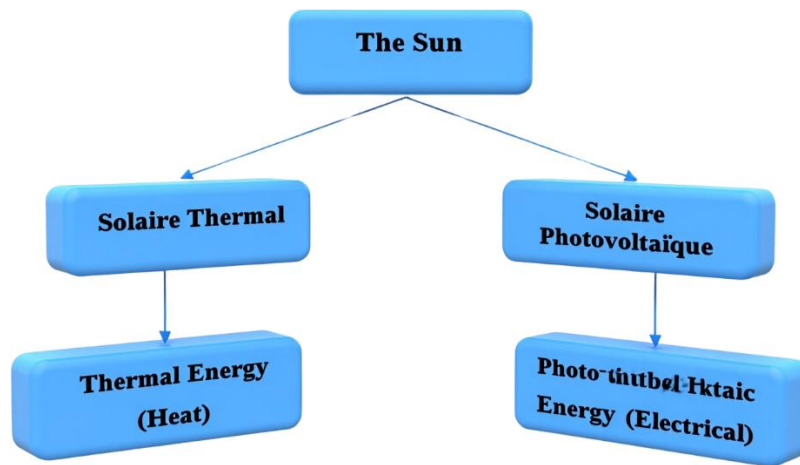


Figure I. 1: shows the solar system.

I.4.1 Solar photovoltaic energy

Solar photovoltaic energy, a renewable type, employs photovoltaic cells to generate electricity by changing solar radiation. These panels serve individual functions, such as charging batteries for personal electricity needs. Alternatively, they operate on a larger scale in photovoltaic plants to supply power to the public grid.

I.4.1.1 Operation

A photovoltaic system is made up of photovoltaic cells that hold layers of semiconductors, usually silicon. When sunlight hits a cell, it moves electrons and creates a direct electric current. An inverter changes this current into alternating current, which is then ready for use in household electrical devices.

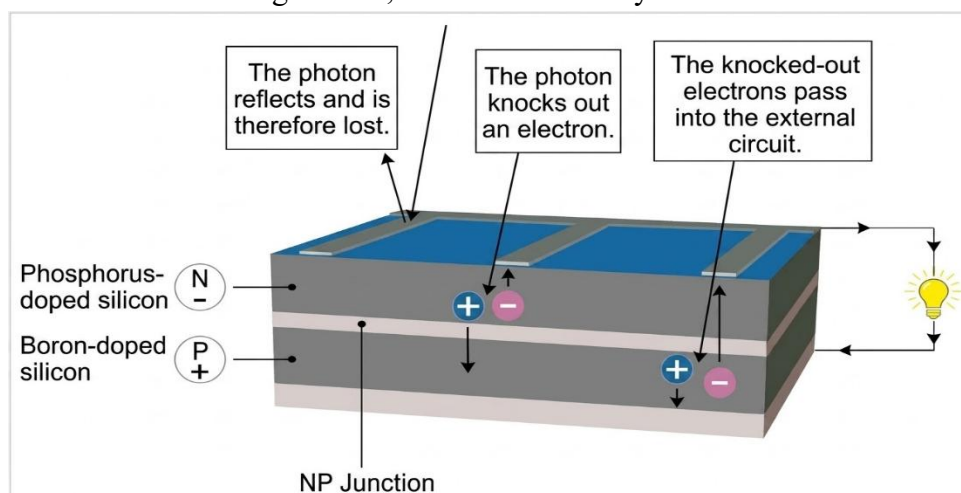


Figure I. 2: Photovoltaic cell diagram.

I.4.2 Solar thermal energy

Solar thermal tech uses solar collectors to absorb sunlight with a heat transfer fluid, like air or water. This captured energy can then be used for heating buildings, heating water, heating pools, and heating spaces.

I.4.2.1 Operation

A solar collector includes an absorbing surface, a fluid to carry energy, a frame, and thermal insulation.

Solar collectors employ an absorbing surface to gather energy from the sun. The internal frame boosts the collector's efficiency, and then a heat transfer fluid moves this energy as heat. This heat travels through insulated pipes to warm cold water. Several technical advances exist in solar thermal collectors:

- ✓ Treated glass allows about 95% of light to pass through because of its low iron oxide content.
- ✓ Transparent vacuum tubes can cut down on heat loss from the absorber due to convection.

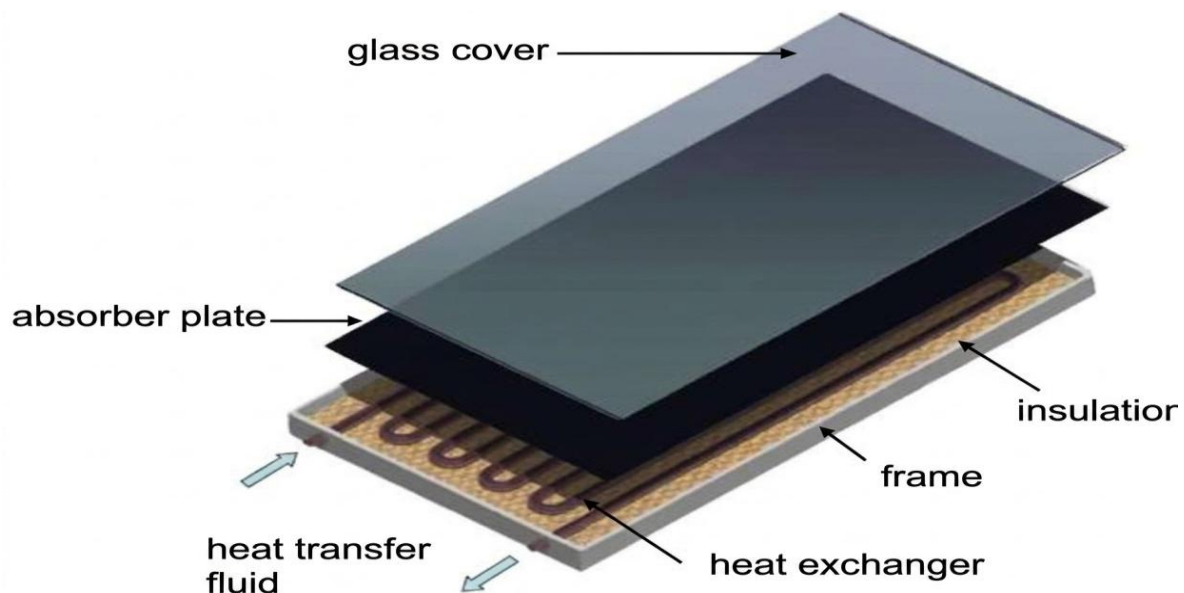


Figure I. 3: thermal sensing apparatus illustration

I.5 Domestic hot water (DHW)

Renewable energy has ascended to prominence on a global scale, with solar energy emerging as one of the most extensively utilized forms across diverse applications and multiple sectors. Through advancements in technology, solar energy has established itself as a pivotal resource for the generation of domestic hot water by harnessing solar radiation. It is imperative to possess a system that is comprised of the following components: a capture mechanism, a storage unit, a backup mechanism, and a distribution framework. Solar energy must possess the capacity to satisfy the demands of its users.

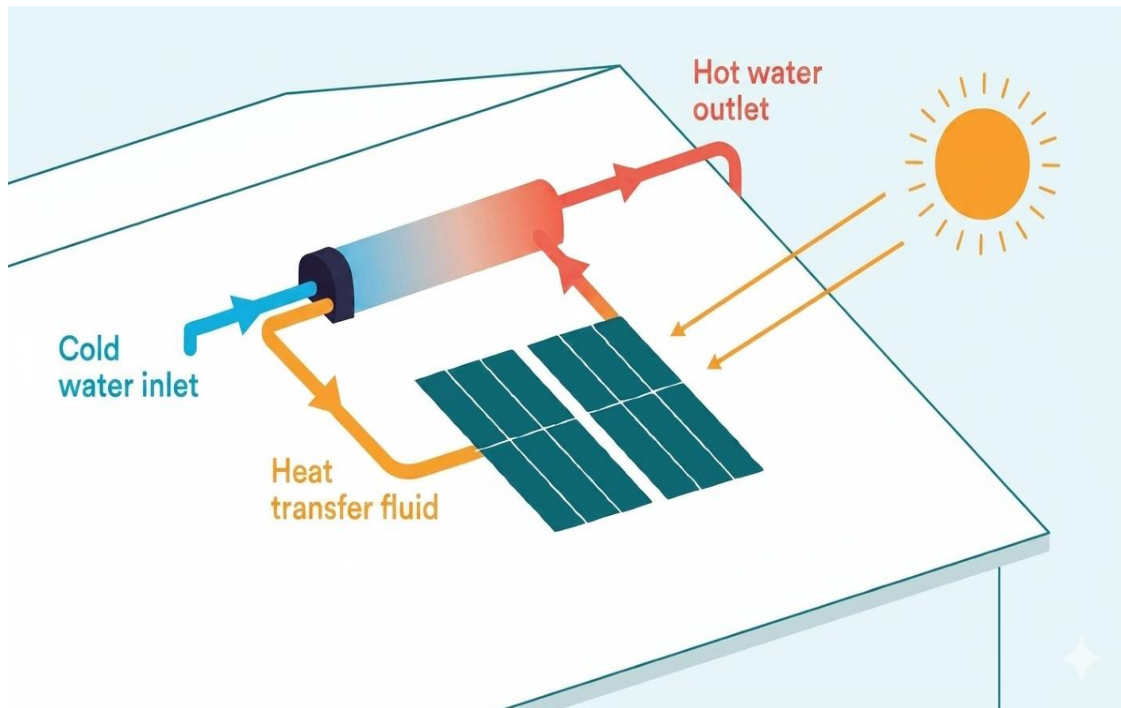


Figure I. 4: Schematic Diagram of a Solar Water Heater

Operating Parameters and Characteristics of Solar Collectors:

- ✓ Solar radiation parameters
- ✓ Cross-sectional area of the fluid flow
- ✓ Ambient temperature
- ✓ Wind speed over the collector
- ✓ Position parameters : inclination and orientation
- ✓ Collector dimensions: thickness, length, width, and absorber surface area
- ✓ Heat transfer fluid flow rate

I.6 Renewable energy in the world

Many countries are increasingly focusing on the development of renewable energy, as it plays a crucial role in addressing climate change challenges and ensuring a sustainable energy supply for the future.

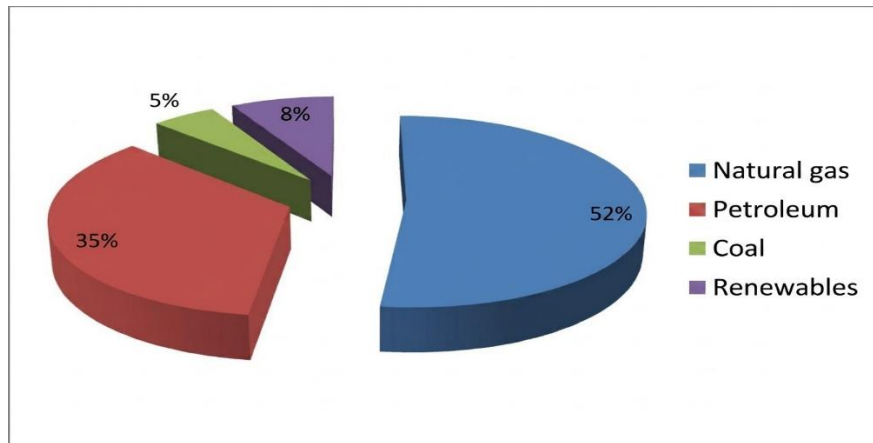


Figure I. 5: Predicted distribution of primary energy demand by energy source

The use of solar energy has been expanding rapidly and is becoming increasingly widespread compared with other energy sources. Solar energy has gained significant importance in many sectors worldwide, particularly in solar water heating systems.

Solar water heaters are continuously developing and are widely used across different fields, such as swimming pool heating and residential space heating. *Figure I. 6* above presents the solar water heater market distribution by region and across various sectors.

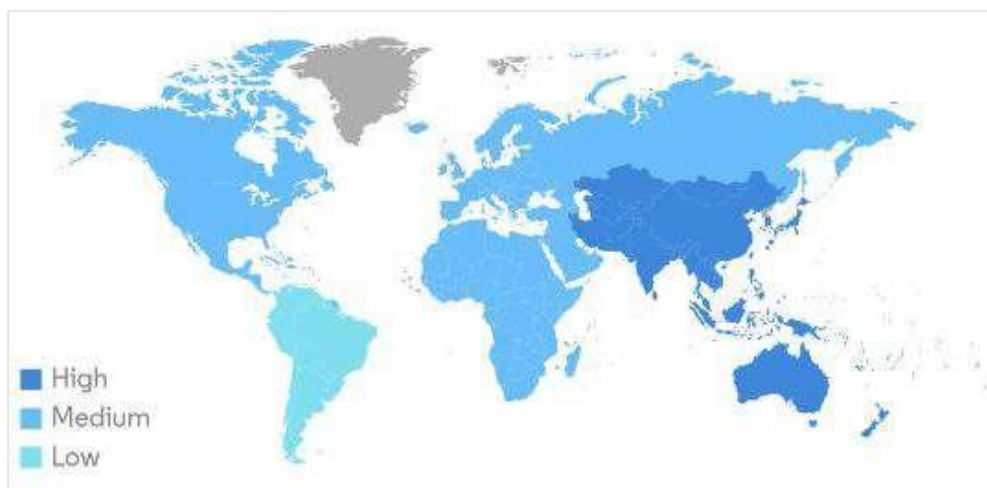


Figure I. 7: Solar Water Heater Market — Growth Rate by Region

I.7 Advantages of renewable energy

In comparison with fossil and nuclear energy, renewable energy sources are considerably cleaner. Throughout production, operation, and decommissioning, they are more environmentally friendly. Moreover, they are safe, widely accessible, and freely available once the production system becomes economically viable.

Renewable energy is considered environmentally sustainable as long as its primary sources include:

- ✓ Wind energy
- ✓ Marine energy
- ✓ Solar energy
- ✓ Energy from waste (biomass)
- ✓ Géothermal energy

Considering these characteristics, it is essential to examine each type of energy individually, and even each specific case, in order to determine whether the expected benefits can actually be achieved.

Wind energy is considered one of the most environmentally friendly energy sources, as it produces neither emissions nor waste during operation. It provides a strong level of energy independence, both onshore and offshore. Wind turbines have significant power generation capacities and represent a viable solution for remote regions where access to electricity is limited or difficult.

Biomass energy is commonly associated with the combustion of wood, which is a widely available fuel. Although this process produces greenhouse gases, the emissions are generally lower than the amount of CO₂ absorbed by a tree during its lifetime. Proper forest management and continuous reforestation are therefore essential to maintain sustainable wood resources.

Solar energy is widely recognized in the energy sector and has experienced rapid growth in recent years. Photovoltaic technology enables the production of electricity, while solar thermal systems allow the generation of heat. Solar energy can be exploited on a large scale in specially designed solar farms, or on a smaller scale in residential installations.

Hydropower is a renewable energy source that produces relatively low greenhouse gas emissions while ensuring reliable electricity generation with reduced operating costs. In addition, hydropower contributes to local economic development and can support irrigation systems and flood management. However, it is important to carefully consider its potential environmental and social impacts.

Geothermal energy represents a sustainable and renewable energy source capable of providing stable and continuous power generation with low greenhouse gas emissions. After the initial investment, geothermal systems generally have low operating costs and a limited environmental impact. Furthermore, geothermal energy can be used flexibly for both electricity generation and heating, while creating local employment opportunities and strengthening regional economies.

I.8 Reduction of CO₂ emissions

The integration and expansion of renewable energy sources play a fundamental role in combating climate change. By adopting technologies such as solar, wind, hydroelectric, and biomass energy, it is possible to gradually reduce our dependence on fossil fuels, which are the main contributors to CO₂ emissions.

Unlike fossil-fuel-based power plants, renewable energy systems have the advantage of producing electricity and heat without emitting CO₂ during their operation. Furthermore, continuous technological advancements in the field of renewable energy have made these energy sources increasingly economically competitive, thereby encouraging their large-scale deployment.

Investing in renewable energy infrastructure not only contributes to the reduction of CO₂ emissions but also promotes innovation, creates green jobs, and enhances the diversification of energy supply sources.

Transitioning to renewable energy is therefore essential. It contributes to the development of a cleaner energy mix, reduces greenhouse gas emissions, and ensures a safer and more sustainable future for future generations.

I.9 The solar energy source

La source d'énergie solaire repose sur la luminosité du soleil. Grâce à la lumière du soleil captée par les capteurs solaires, cette énergie permet de générer de l'électricité ou des centrales solaires thermiques.

Si le soleil est loin de nous, à plus de 150 millions de kilomètres, il reste notre principale Source d'énergie, même si elle est sporadique.

Il s'agit d'une énergie écologique qui ne produit aucun gaz à effet de serre et sa source, le soleil, est libre et inépuisable à travers le monde

I.9.1 The sun

Our solar system orbits a central star known as the Sun. Its composition is primarily hydrogen (78.4% by mass) and helium (19.6% by mass), while the remaining 2% consists of other chemical elements, among which oxygen and carbon are the most abundant. The temperature at the Sun's core is approximately 10^7 K. At this extremely high temperature, nuclear fusion reactions occur, converting hydrogen into helium. This process releases a massive amount of energy, equivalent to about 4.109kg/s of mass energy.

I.9.2 Solar radiation and sources

However, a large portion of solar energy is not transmitted to the Earth. Measured at the top of the Earth's atmosphere, the average solar irradiation reaches 1,368 W/m². This measurement, known as the solar constant, represents the power received per square meter of surface. The actual amount of solar radiation reaching the surface depends on various factors, including the solar elevation angle, which varies throughout the day.

As solar radiation passes through the atmosphere, part of it is scattered and absorbed by elements such as air molecules, atmospheric impurities, and water vapor. The intensity of solar radiation reaching the surface also depends on the air mass through which it travels. When the Sun is directly overhead at a point on Earth, the radiation travels the shortest path through the atmosphere, which occurs only at certain times of the year between the Tropics.

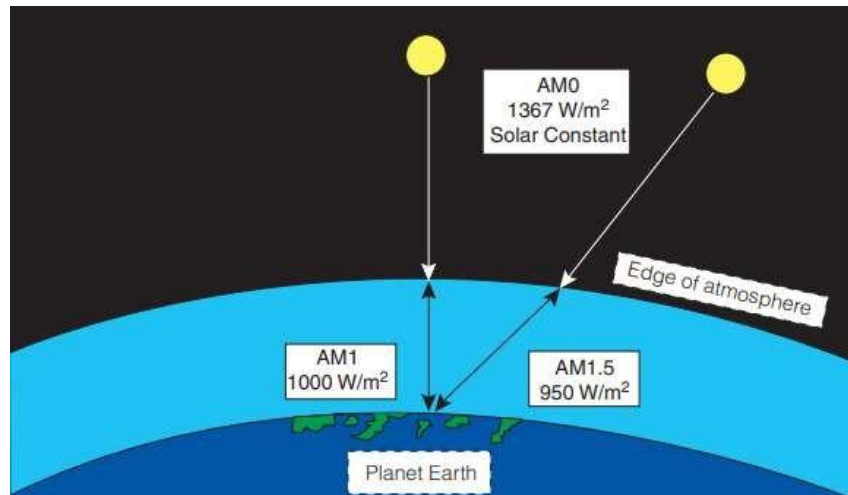


Figure I. 8: The Amount of Irradiation Reaching the Earth's Surface Is Affected by the Medium It Passes Through

I.9.2.1 Illuminance

Illuminance is defined as the energy received by a surface. It is expressed in W/m^2 (watts per square meter).

I.9.2.2 Irradiation

The energy absorbed by a surface is referred to as irradiation. It is expressed in J/m^2 (joules per square meter).

The total amount of radiation absorbed on a given surface is determined by the sum of three components:

Direct solar radiation: This is the portion of solar radiation that passes through the atmosphere directly from the Sun. This component becomes zero when the Sun is obscured by clouds or obstacles.

Diffuse radiation: This represents the portion of solar energy scattered by the atmosphere and redirected toward the Earth's surface.

Reflected radiation: This refers to the radiation reflected by the surrounding environment, particularly the ground, whose reflectivity is known as the albedo

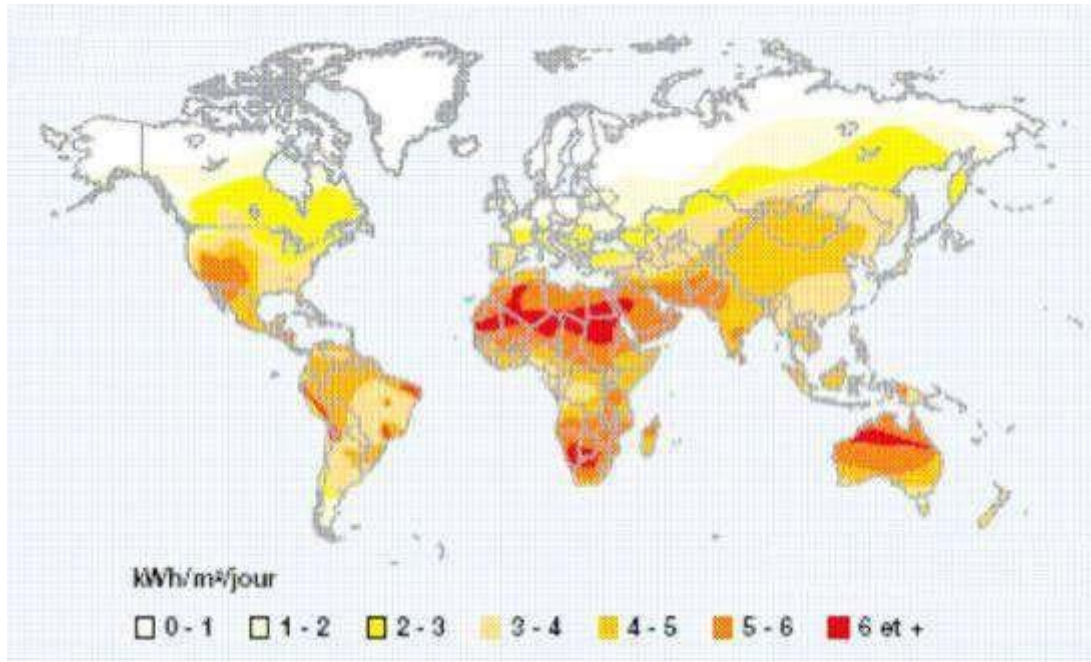


Figure I. 9: World Map of Average Annual Solar Irradiation in kWh/m²/day on a Horizontal Plane.

I.9.3 Solar radiation available on earth

To properly size a solar installation system, it is essential to determine the amount of solar energy available.

At a given location, three components are combined to form the incident radiation, referred to as global Solar radiation types

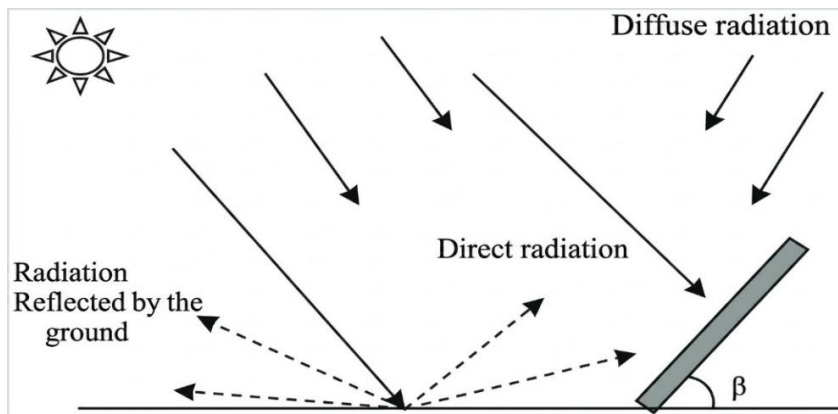


Figure I. 10: The Three Types of Solar Radiation

I.9.3.1 Direct solar radiation

Direct solar radiation refers to sunlight that reaches a specific surface without being obstructed, emitted from a solid angle around the solar disc.

I.9.3.2 Diffuse solar radiation

Diffuse solar radiation represents the sunlight scattered by various obstacles, arriving from all directions.

I.9.3.3 Global solar radiation

Global solar radiation is the total shortwave radiation reaching a horizontal surface at the ground. It includes both direct solar radiation and diffuse solar radiation resulting from reflected or scattered light.

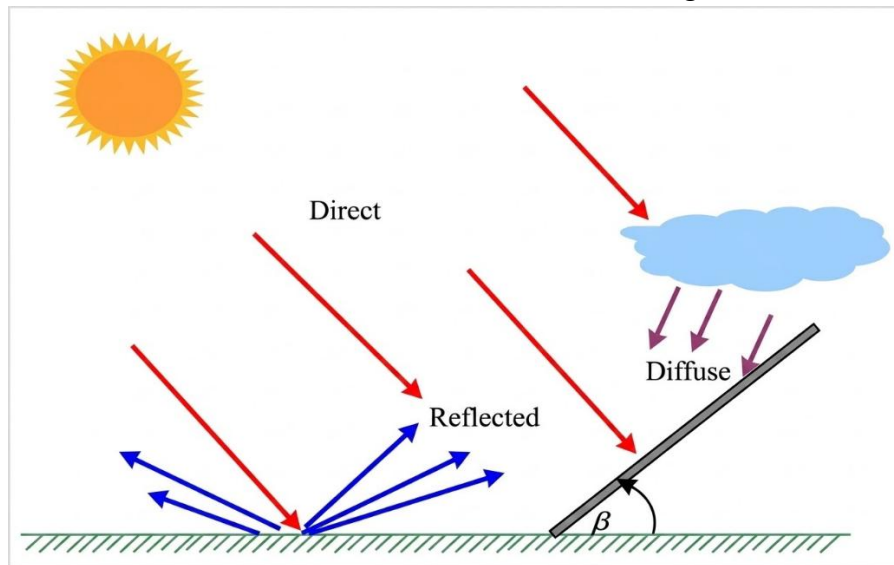


Figure I. 11: Components of Solar Radiation

I.10 Solar radiation in algeria

Due to its geographic location, Algeria is among the country's richest in solar resources worldwide and has the potential to become an attractive source of solar energy. Considering the annual sunshine duration recorded across most of the country, it exceeds 2,000 hours per year, while in the High Plateaus and Sahara regions; it reaches up to 3,900 hours.

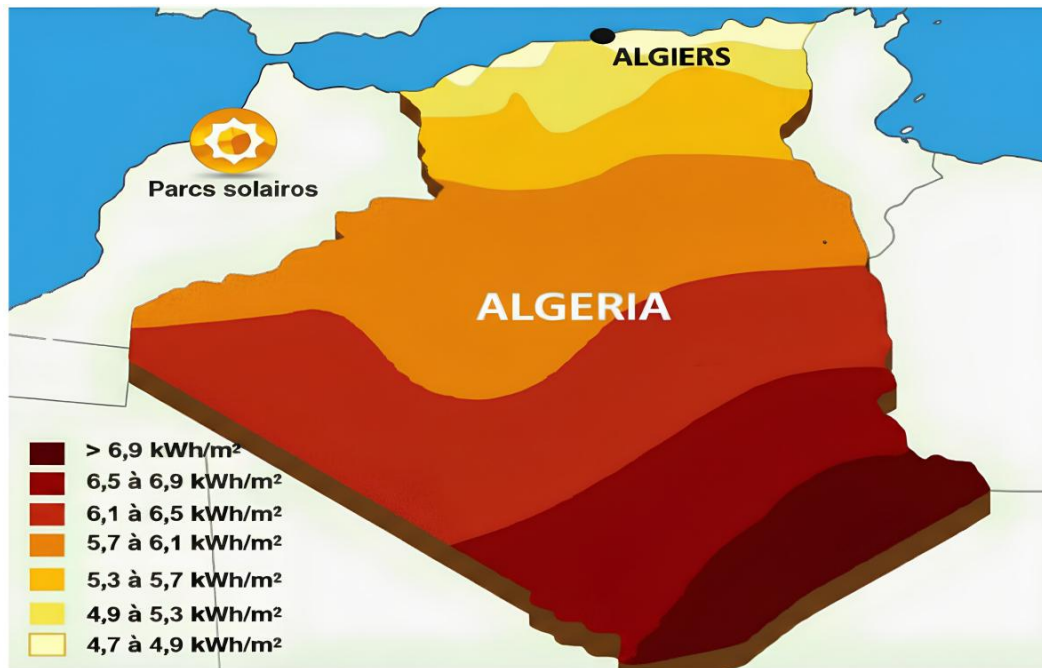


Figure I. 12: Solar Irradiation Map of Algeria

Table I. 1: Solar Irradiation across Different Regions of Algeria.

Regions	Coastal Region	High Plateaus	Sahara
Surface Area (%)	4	10	86
Average Duration of Sunshine (Hours/year)	2650	3000	3500
Average Received Energy (Kwh/m2/year)	1700	1900	2650

I.11 Earth and sun motion

The Earth represents one of the focal points due to its elliptical orbit around the Sun. This orbit lies within the plane of the ecliptic

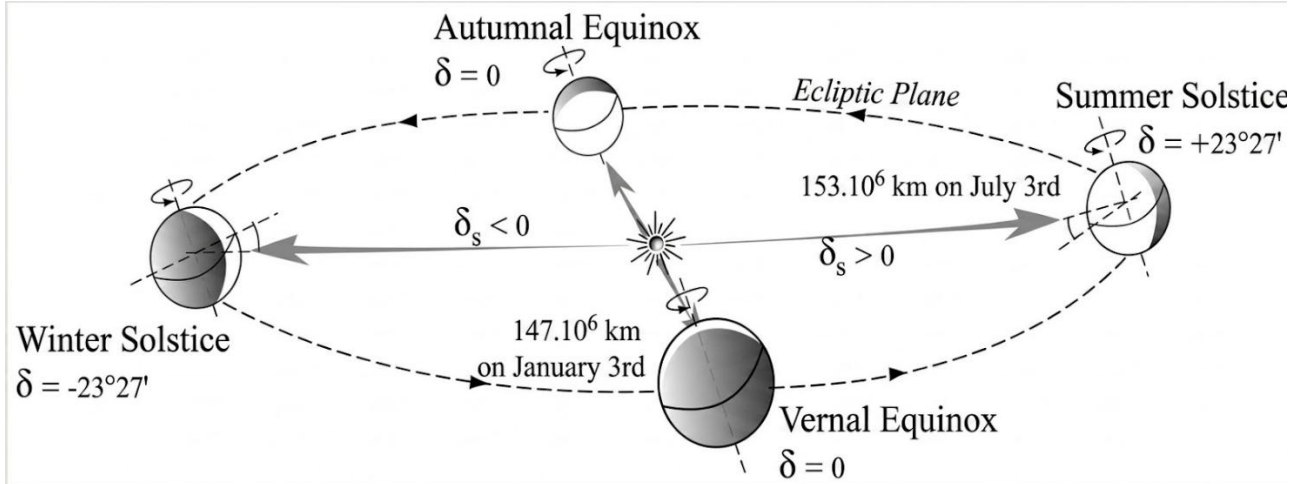


Figure I. 13: The Sun's Position at a Site Varies According to the Earth's Rotation and Revolution Around the Sun.

The Earth also rotates continuously on its axis, moving uniformly from west to east. This rotation is responsible for the daily cycle of day and night.

The Earth's rotational axis maintains a stable direction throughout the year, tilted at an angle of $66^{\circ}33'$ relative to the plane of the ecliptic. This tilt explains the variation in day and night durations across the seasons. For an observer on Earth, this creates the apparent motion of the sun from east to west across the sky.

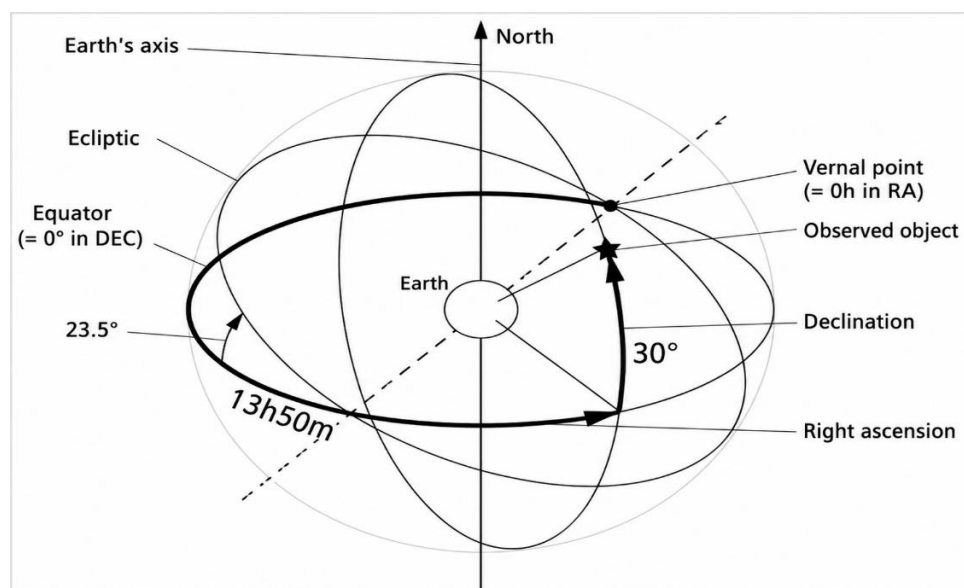


Figure I. 14: Celestial Sphere

I.11.1 Geographic coordinates

To determine the position of the sun from any location on Earth, it is essential to specify the geographic coordinates of that location.

I.11.1.1 Latitude (Φ)

Latitude indicates the position of a point relative to the equator and ranges from 0° to 90° , being positive north of the equator and negative south of the equator.

If $\Phi > 0$, the location is in the Northern Hemisphere; otherwise, it is in the Southern Hemisphere.

I.11.1.2 Longitude (L°)

The longitude of a specific location is the angle formed between the meridian passing through that location and the prime meridian (Greenwich Meridian).

It ranges from 0° to 180° , positive toward the east and negative toward the west.

I.11.1.3 Altitude (z)

Altitude is the height of a location relative to mean sea level, expressed in meters.

I.11.1.4 Meridian

A meridian is a semicircle on the Earth that passes through the North and South Poles. All points along the same meridian share the same longitude. The reference meridian for longitude is the Greenwich Meridian. The meridian plane at a given location is defined by that location and the Earth's rotational axis.

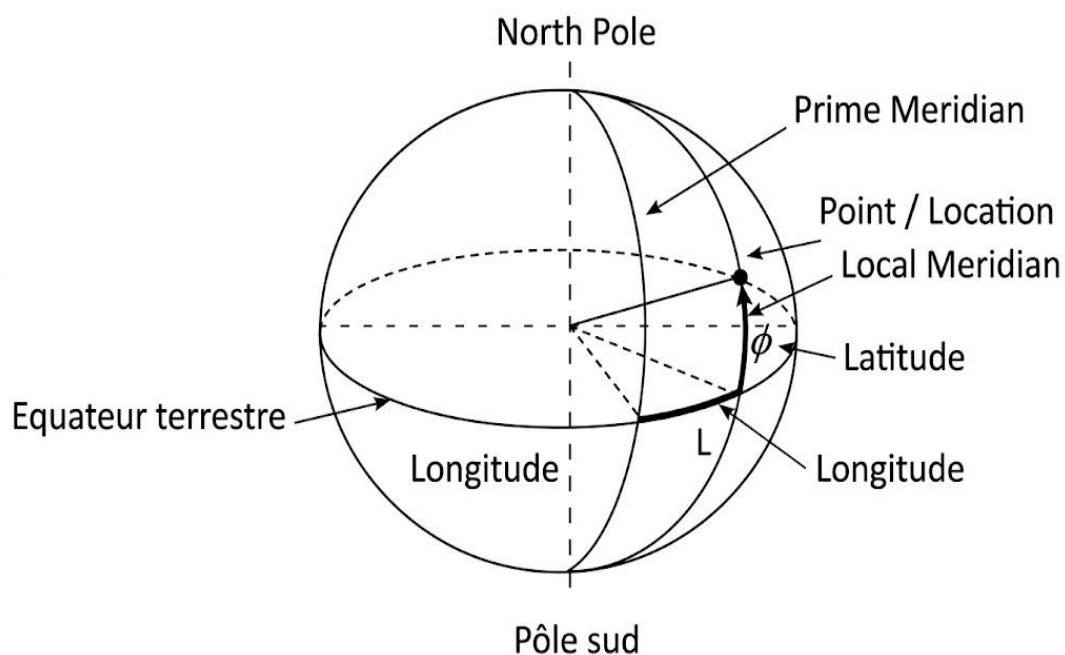


Figure I. 15: Geographic Coordinats

I.11.2 Hourly celestial coordinates

I.11.2.1 Solar declination (δ)

The solar declination is the angle formed between the Earth's equatorial plane and the line connecting the Earth to the Sun, projected onto the equatorial plane. It reflects the tilt of the equatorial plane relative to the plane of the ecliptic. It is also defined as the angle between the Earth's rotational axis and the line connecting the Earth to the Sun.

The vertical passing through the center of the Earth defines a reference axis. The value of this angle varies throughout the year, with a minimum of $-23^\circ 27'$ and a maximum of $+23^\circ 27'$.

I.11.2.2 Hour angle (ω)

The hour angle is a concept determined by the regular rotation of the Earth on its axis. It represents the angular displacement of the sun along its apparent path relative to the meridian plane of the observation location. The hour angle is calculated using the following relationship:

$$\omega = 15 (TSV - 12) \quad (\text{I}, 1)$$

TSV: True Solar Time

ω : Hour angle [deg]

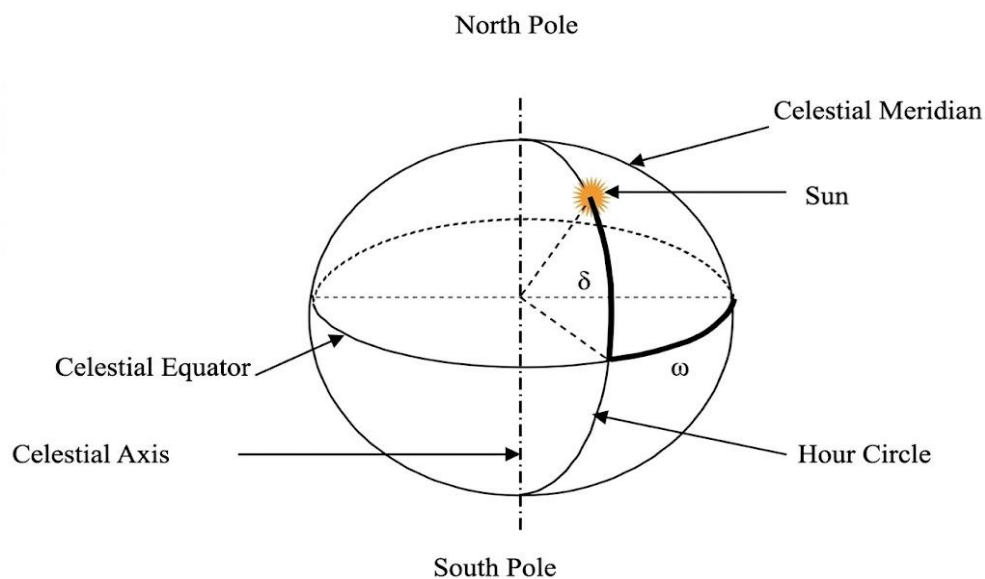


Figure I. 16 : Hour Angle Coordinates

I.11.3 Horizontal celestial coordinates

The horizontal coordinate system is defined by the plane of the astronomical horizon and the local vertical. In this system, the sun's coordinates are:

I.11.3.1 Solar Altitude (h)

The solar altitude angle h is the angle between the sun's direction and its projection onto a horizontal plane. It is given by the following expression:

$$\sin(h) = \sin(L) \times \sin(d) \times \sin(L) \times \cos(d) \times \cos(\omega) \quad (\text{I, 2})$$

I.11.3.2 Solar azimuth (a)

The azimuth angle represents the angle between the local meridian and the vertical plane intersecting the sun. It is calculated using the following formula:

$$\sin(a) = \cos(d) \times \sin(\omega) / \sin h \quad (\text{I, 3})$$

- a: Solar azimuth angle [deg]

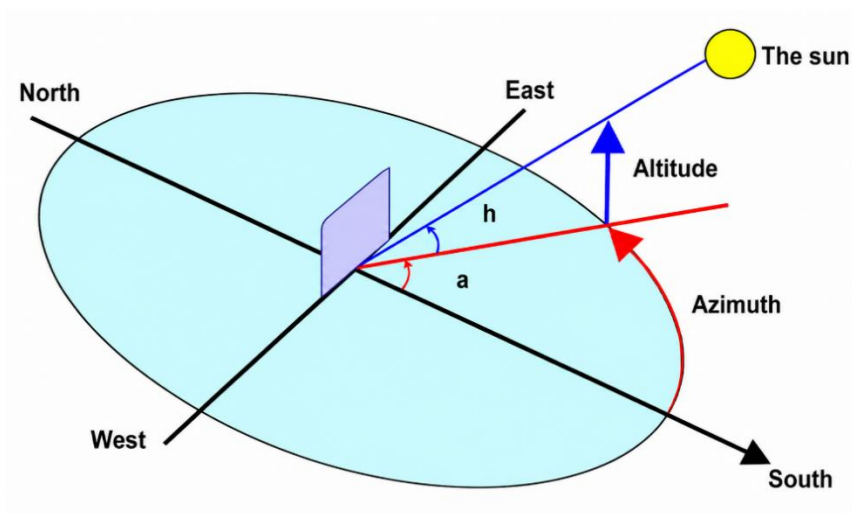


Figure I. 17: Coordinats That are horizontal

I.11.3.3 Angle zenithal (Θ_z)

The difference between the line connecting the observer to the sun and the local zenith direction is known as the zenith angle. The range of its value is 0° to 90° .

$$\Theta_z = 90 - h \quad (\text{I,4})$$

where h is the angle of solar altitude.

I.12 Apparent trajectory of the sun

For an observer on the Earth's surface, the sun follows an apparent trajectory in the sky, which varies according to the latitude and longitude of the observation location.

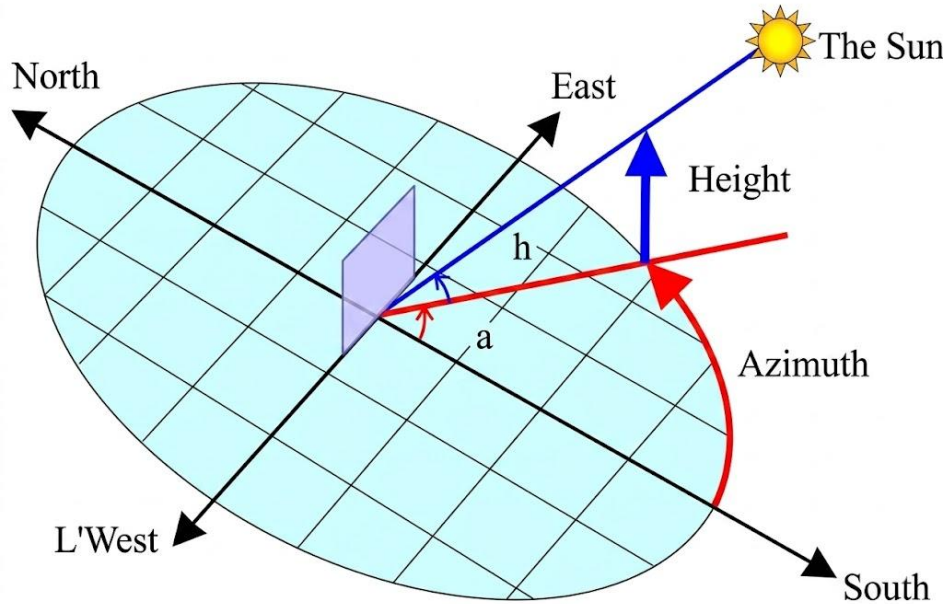


Figure I. 18: Apparent Motion of the Sun

I.13 Emission from bodies

The surrounding space and anybody with a temperature above absolute zero emit radiation, the energy of which is distributed over a spectral region corresponding to a wavelength interval, $\Delta\lambda$.

The solar spectrum ranges from $0.2\ \mu\text{m}$ to $25\ \mu\text{m}$. Outside the atmosphere, most of the solar energy lies in the $0.2\text{--}4\ \mu\text{m}$ band, whereas at the Earth's surface, it falls within the $0.29\text{--}3\ \mu\text{m}$ range.

Thermal radiation is defined as the radiation emitted within the spectral interval of 10^{-1} to $100\ \mu\text{m}$, corresponding to the emission of bodies at temperatures of interest.

I.13.1 Emission from a Black Body

By definition, a black body is a perfect absorber, meaning it absorbs all incident radiation. In practice, a surface coated with soot is a fairly good approximation of a black body.

The spectrum of a black body is represented by the following curve: $M^0 \lambda = M^0(\lambda, T)$ where $M^0 \lambda$ is the monochromatic emission, i.e., the amount of energy emitted per unit wavelength interval by a unit area of the emitting surface. The shaded area under the curve represents the energy emitted over that wavelength range. Changes in temperature affect the black body spectrum, particularly the shift of the peak wavelength.

The total energy (generally thermal energy) emitted by a body into a half-space (with a solid angle

of 2π steradians) is obtained by integrating the monochromatic emission over all wavelengths:

$$M^0 = \int M_\lambda^0 d\lambda \quad (\text{I, 5})$$

According to Planck's law, the theoretical value of M^0 can be determined, which leads to the Stefan–Boltzmann law:

$$M^0 = \sigma \cdot T^4 \quad (\text{I, 6})$$

I.13.2 Emission from a Real Body

The energy emitted by any non-black body per unit surface area and per unit time is expressed as:

$$M = \sigma \cdot \epsilon \cdot T^4 \quad (\text{I, 7})$$

where:

- ϵ ; var epsilon ϵ is the total emissivity of the body, which depends on the temperature of the emitter and its surface condition. Emissivity is high for dark-colored surfaces and relatively low for light-colored surfaces.

I.14 Solar fraction

The amount of light that is absorbed, reflected, or transmitted through a surface—typically a window or glazing—is referred to as the solar fraction, or solar factor. It is usually expressed as a percentage and represents the proportion of the total incident solar radiation that passes through the surface.

The solar fraction is defined by the following equation:

$$FS = Q_{\text{solar}} / Q_{\text{total}} \quad (\text{I, 8})$$

FS : Solar Fraction

Q_solar: The amount of thermal energy supplied by the solar system.

Q_total: The total thermal energy demand.

I.15 Solar energy collection

There are several ways to harness the solar energy that is available on Earth, including

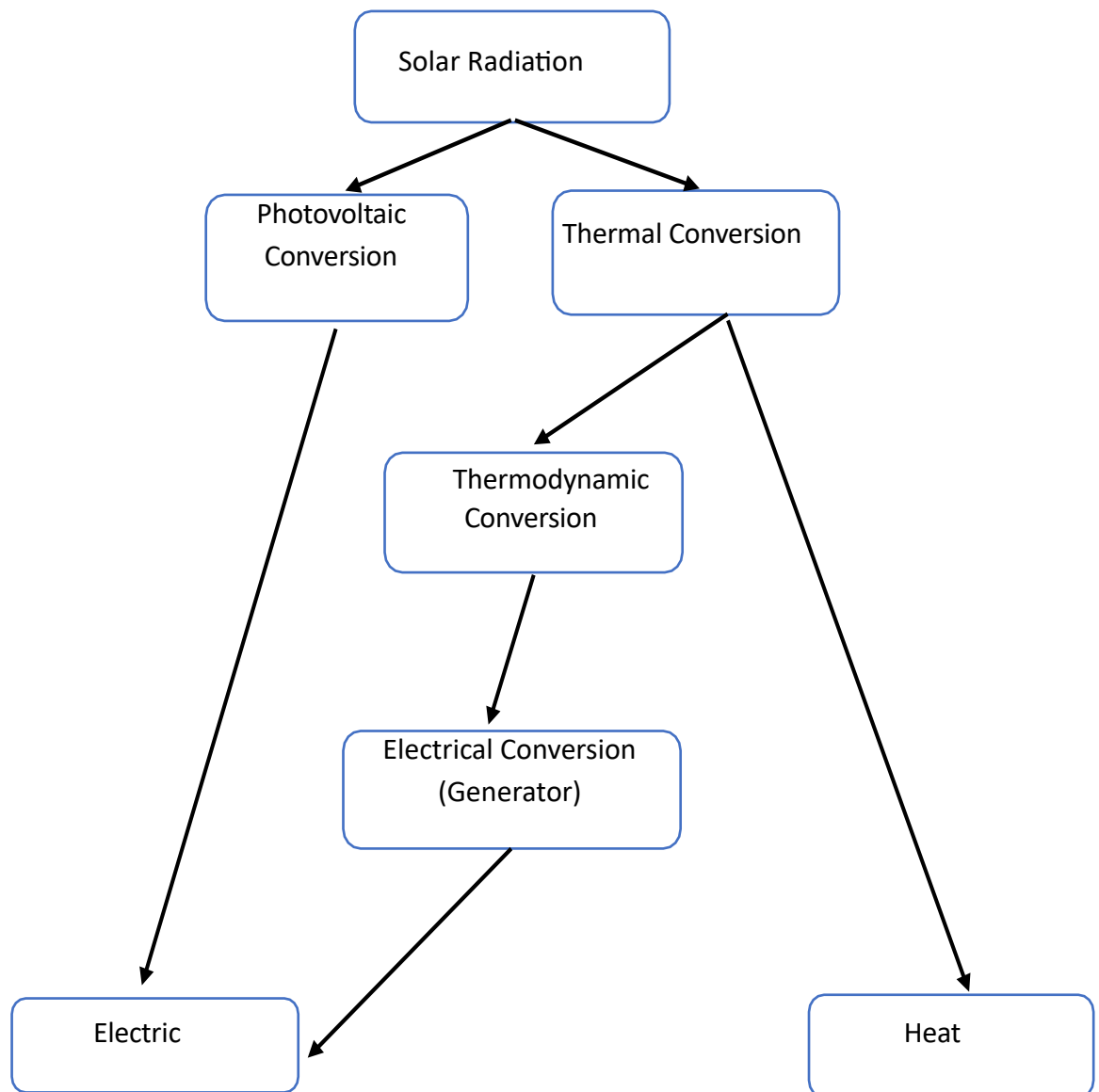


Figure I. 19: Schematic of Solar Energy Capture.

I.15.1 Solar thermodynamic energy

Solar thermodynamic energy uses solar thermal energy to generate electricity following the same principle as a conventional power plant, but employing Helio thermal power stations [35].

Three main types of plants are utilized:

- ✓ Parabolic trough plants, which can reach temperatures between 300 and 350 °C.
- ✓ Parabolic dish plants, which can reach temperatures of 1000 °C or higher.
- ✓ Solar power plants, capable of reaching 1000 °C

I.15.2 Solar photovoltaic energy

Solar energy generates electricity by converting a portion of solar radiation using solar cells. These cells operate based on the photovoltaic effect and consist of layers of semiconductor materials and semiconductor junctions. Silicon is the most commonly used material. Although gallium arsenide offers better performance, it remains significantly more expensive.

I.15.3 Solar thermal energy

Solar thermal energy converts solar radiation into heat and can be applied in various ways:

- ✓ Direct use of heat: solar water heating, space heating, solar cooking, and solar drying.
- ✓ Indirect use: where the captured heat is utilized for other applications.

I.15.3.1 Solar thermal system

A solar thermal system is designed to produce heat, such as for domestic hot water or space heating, by converting solar energy. It captures solar radiation to heat a working fluid, which then transfers the thermal energy to water stored in a tank for domestic use.

I.15.3.2 Heat transfer modes in solar collectors

A solar collector simultaneously employs three modes of heat transfer: conduction, convection, and radiation.

I.15.3.2.1 Conduction heat transfer

Conduction heat transfer is characterized by the propagation of thermal energy within a medium without the motion of matter. Fourier's law of heat conduction governs this process.

$$\Phi = -\lambda.S.grad T \quad (I, 9)$$

Heat transfer by conduction primarily occurs between the upper and lower surfaces of the glass, as well as between the upper and lower surfaces of the insulation within the flat-plate solar collector, and between the absorber and the insulating material.

I.15.3.2.3 Convective heat transfer

Convective heat transfer involves macroscopic fluid motion. Two types of convection can be distinguished:

- ✓ Natural (or free) convection: Fluid motion is induced by simultaneous temperature variations within the medium and the action of a body force field.
- ✓ Forced convection: Fluid circulation is driven by a mechanical means, such as pumps, fans, or similar devices.

Newton's law of cooling governs convective heat transfer:

$$\Phi = h \cdot S \cdot (T_p - T_f) \quad (\text{I, 10})$$

In a flat-plate solar collector, convection either occurs between the glass cover and the surrounding environment, through natural (free) convection or forced convection due to wind.

- ✓ The absorber operates via natural convection between the glass cover and the absorber plate.
- ✓ Natural convection occurs within the tube and the working fluid.
- ✓ Natural convection between the fluid and the insulating material.
- ✓ Natural or forced convection due to wind between the insulation and the surrounding environment.

I.15.3.2.3 Radiative heat transfer

When a surface emits energy in the form of electromagnetic waves and simultaneously absorbs it, this results in heat transfer by radiation. This exchange can occur even when a vacuum or any other intermediate medium that is sufficiently transparent to electromagnetic waves separates the bodies.

The Stefan–Boltzmann law represents the fundamental principle governing radiation:

$$\Phi = \varepsilon \cdot S \cdot \sigma (T_p^4 - T_f^4) \quad (\text{I, 11})$$

- ✓ Radiative heat transfer occurs in a solar collector between:
- ✓ The glass cover and the absorber
- ✓ The window and the sky
- ✓ The insulating material and the ground

I.16 Conclusion

Algeria possesses one of the highest solar potentials in the world, particularly in its southern regions, due to its favorable geographical location and climatic conditions. The abundant and consistent solar irradiance makes solar energy a highly viable, clean, and sustainable solution to meet the country's growing energy demands.

Harnessing this resource offers multiple benefits, including environmental protection, energy independence, and economic development. Understanding the characteristics of solar radiation, such as its intensity, seasonal variations, and distribution across the country, is essential for designing efficient solar energy systems.

In summary, the sun's energy represents a strategic opportunity for Algeria to transition towards renewable energy, reduce reliance on fossil fuels, and promote sustainable development, laying a solid foundation for the deployment of photovoltaic, solar thermal, and hybrid energy systems in the following chapters.

Chapter II: Solar Heating System

II.1 Introduction

Solar heating systems are widely used to convert solar radiation into thermal energy for practical applications such as domestic hot water production and space heating. Among these systems, the combination of a solar collector with a hot water storage tank is one of the most efficient and commonly used configurations, especially in regions with high solar potential such as Algeria.

This system ensures a continuous supply of hot water by storing thermal energy during periods of high solar irradiation and using it when solar energy is unavailable.

II.2 Presentation of system studied

II.2.1 Description general of system of water heater solar

The system water heater solar East allow to use energy solar, for different applications such that the heating and the water heater. And to harness this energy in a useful way, a system consisting of solar collectors, pipes, a storage tank, a pump... is required.

The solar collector captures solar energy and converts it into heat. This absorbed heat then transferred through pipes via a heat transfer fluid to the storage tank, where it transfers its heat to the cold water in the insulated storage tank. A controller automatically adjusts the system according to weather conditions and the need for hot water.

Once the heat transfer fluid has cooled, it returns to the solar collector to be heated again. When the heated water is used, cold water replaces the used water, which then heated in the same way.

This system sustainable East a solution energy ecological for their production hot water

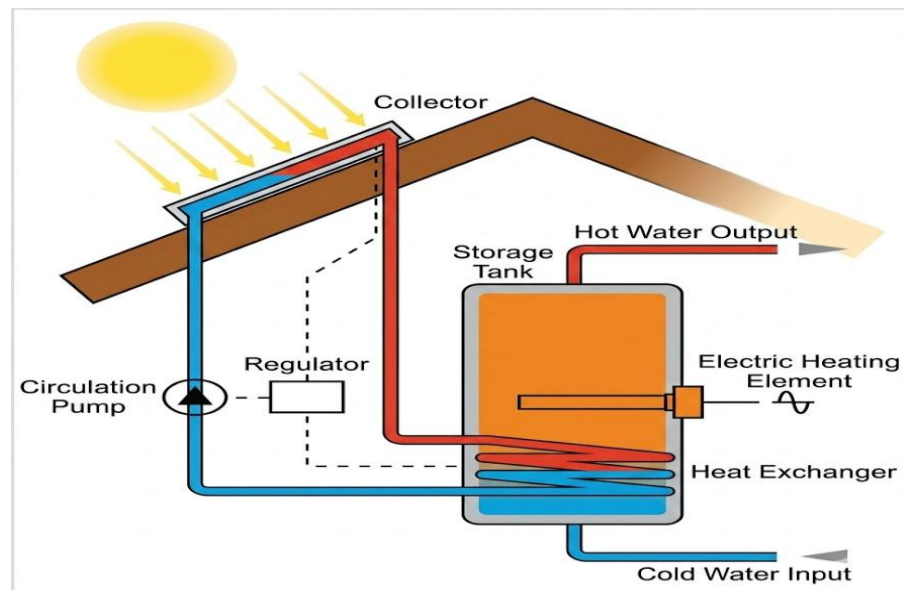


Figure II. 1: plan of a water heater solar

II.2.2 Importance and application of system

Energy plays a key role in all aspects of modern life (industry, transport, agriculture, etc.). In addition, with development, renewable energy has conquered the world because it is environmentally friendly. Solar water heaters rely on sunlight. Our system provides an economical solution for our energy bills and environmental sustainability. A solar water heater primarily used to heat domestic water, but our system can be used for other applications:

II.2.2.1 System solar combined (SSC)

It works like a solar water heater; however, solar heating systems are more extensive because the energy requirements for heating premises are generally much greater.

Solar heating of premises, the demand for heat is quite seasonal, whereas domestic water heaters are needed all year round.

This system uses solar energy to cover part of the heating and domestic hot water needs. The solar thermal system combines domestic hot water heating and home heating. The heat transfer fluid transfers its heat to the heating water network, which is also stored in a tank, and always via a heat exchanger.

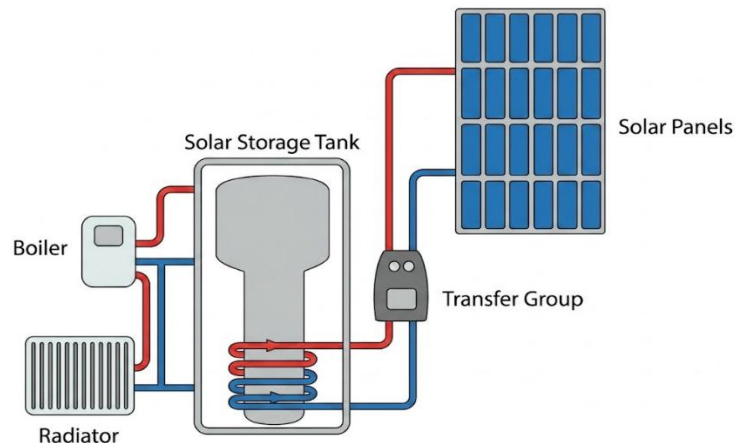


Figure II. 2: plan se system solar combined

There are two categories of combined solar systems:

- ✓ The system solar combined with storage of water of heating in ball:

The functioning of this system rest on the storage of water hot solar in a reservoir to transmit their heat all at long of the day.

- ✓ The floor solar direct (PSD):

The floor solar direct works of there even manner that an SSC with storage, but he born does not require of reservoir.

II.2.2.2 Heating pool

He East among the applications the more profitable of the use of energy solar, For different networks:

- ✓ Their season during which the swimming pools are used correspond has that Who offer the best sunshine (May to September)
- ✓ Efficiency of a sensor solar thermal East vice versa proportional has there temperature fluid Who the crossing
- ✓ THE cost of functioning East very weak

II.3 Principle of functioning of the components

II.3.1 Sensors solar

A solar collector, also known as a solar energy receiver, is a device that converts sunlight into heat. It is an essential component in a solar water heating system. to produce energy.

II.3.1.1 Principle of functioning

Heat receivers (sensors) use an absorbing surface to collect solar radiation this surface

exchanges the absorbed heat with the heat transfer fluid and transfers it to the reservoir. In addition, as it heats up, it emits thermal radiation of a longer wavelength (Stefan - Boltzmann laws).

When the collector is directly in contact with the air ambient, the sudden of the losses by radiation and convection.

To minimize these losses, the absorber is positioned in a frame, and the internal walls of the latter are provided with a thermal insulating layer.

For sunstroke of face of their surface achieved a lid transparent.

II.3.1.2 The types of different sensors

In solar water heating systems, there are several types of solar collectors. To meet different needs, several types of collectors have been developed.

II.3.1.2.1 The sensors plan glazed

Glazed solar collectors are simple collectors with a transparent glazed surface; they are more suitable for applications requiring temperatures between 30°C and 70°C (water heating system, heating, etc.).

He is composed of a frame, insulation thermal, absorbent, transparent surface).

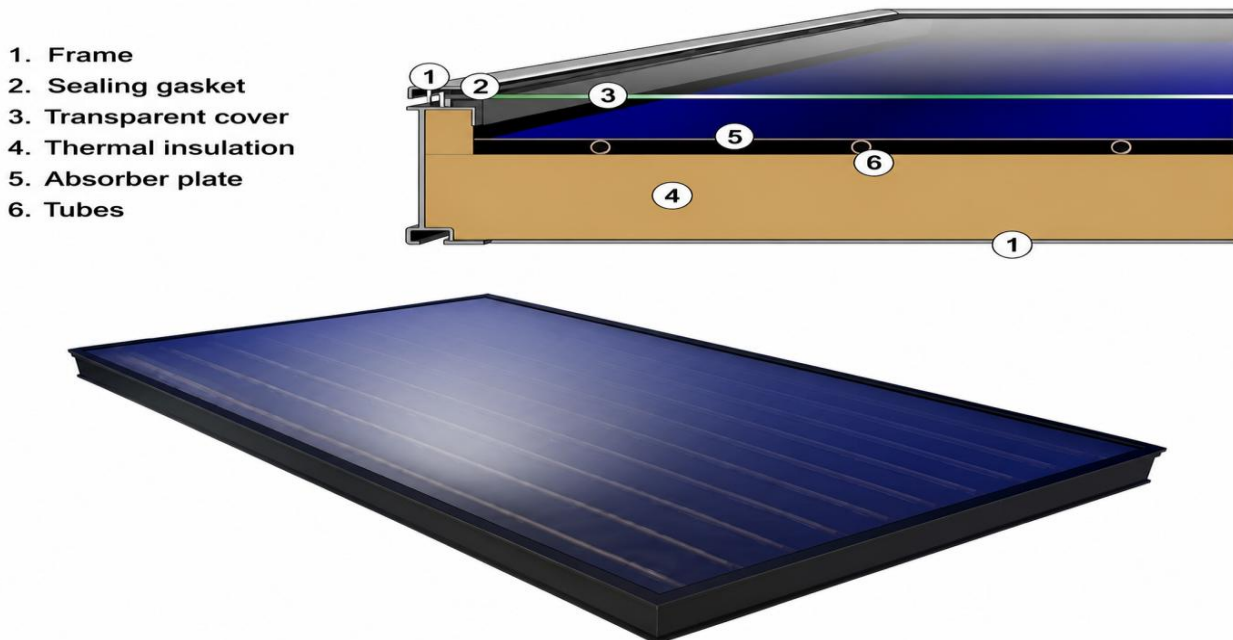


Figure II. 3: plan of a sensor plan

II.3.1.2.2 The non-sensors glazed

It is the kind the simpler and the more affordable but also the less efficiency, he East Compound:

- ✓ From one absorbent of matter metallic or synthetic.
- ✓ And of the tubes cylindrical containing the heat transfer fluid.

He can however, se reveal very efficient when he East used in the applications following: heated pool and other applications of low temperature.



Figure II. 4 : The sensor solar No glazed

II.3.1.2.3 The sensors below empty

The sensor solar below empty has a good performance; he answers to needs applications that require very high temperatures.

This kind of sensor used the empty as insulation thermal for minimize the losses of heat and SO allow increasing yield (between 50% and 70 %).

They are capable of generate of the temperatures until 150°C.



Figure II. 5: tubes under a vacuum installed in a roof.

II.3.1.3 The components of a sensor solar thermal plan

The solar panel is composed of several elements. Its structure is mainly composed of an absorber, of a fluid heat transfer fluid, a blanket transparent, thermal insulation and a box.

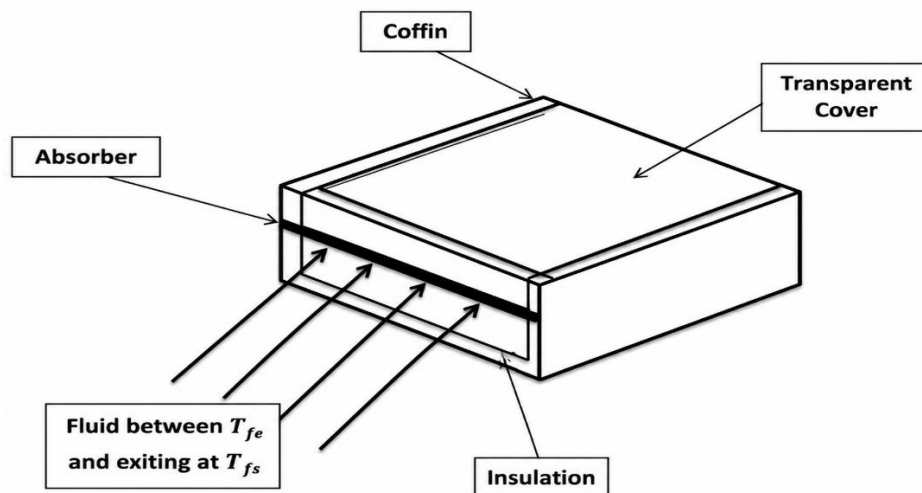


Figure II. 6: components of a sensor solar.

II.3.1.3.1 The box or chest

Develop a robust and secure frame for the sensor. It protects the internal components from weather conditions, shocks, and other mechanical damage. The most commonly used materials for the base of the casing are aluminum or steel.

II.3.1.3.2 Insulation thermal

Thermal insulation prevents heat loss by conduction (at the rear and sides of the collector

casing). Polyurethane foam often used, sometimes combined with a layer of mineral wool in contact with the absorber. If temperatures are high, it does not use those phenolic foams, rare and expensive, thus those wools minerals (glass wool and especially rock wool that has the advantage of not absorbing moisture).

II.3.1.3.3 A blanket transparent

Its objective is to transmit as much solar radiation as possible and to avoid the cooling of the absorber, by reducing air convection phenomena and blocking infrared radiation (greenhouse effect).

The materials commonly used are tempered glass (to reduce the risk of accidents in case of breakage). The glazing used has slightly superior optical characteristics compared to standard glazing.

Their distance between there blankets transparent and the absorber varied between 25 And 40 mm. A

space vaster allowed of reduce the losses thermal caused by their convection.

II.3.1.3.4 The absorber

He it is of the element Who transforms the radiation solar in heat and transferred energy Thus, generated towards A fluid heat transfer fluid.

Copper is the most commonly used material because it has excellent corrosion resistance and high thermal conductivity. The absorber can be viewed as a combination.

II.3.1.3.5 The heat transfer fluid

In reason of the terms climatic, A blend water and of glycol East generally used for dispel their heat stored in the surface absorbent.

Compared has water, the air n / A none issue of freeze in winter, none issue of cooking in summer and none issue of corrosion.

However, the air born can be used that for the heating and her transfer of heat East worse than that of water.

In However, what that either the system, the contact between the tube transporting the liquid and there plate absorption must be very waterproof by stamping or welding.

Of even, there distance between the pipes must be calculated with precision in function of diameter pipe, of the thickness of their plate and of the material used.

The tubes of traffic of fluid in contact with the body absorbent are of preferably arranged in parallel rather than in a serpentine pattern.

Balance sheet energy of sensor:

- ✓ For express efficiency thermal of a collector solar flat, a simplified formulation could be the sequel:

$$\eta = \eta^0 - a^1(\Delta T/G) - a^2(\Delta T^2/G) \quad (\text{II.1})$$

$$\Delta T = T_m - T_a \quad (\text{II.2})$$

Thermal efficiency sensor

Postman optical

There transmittance optical of sensor

a^1 et a^2 : Coefficients of loss thermal

T_m : there temperature average of fluid heat transfer fluid in the sensor °C

T_a : there temperature ambient °C

G: irradiation solar (w / m²)

- ✓ **Energy solar incident (Qinci):**

$$Q_{inci} = H_{AS} \times G \quad (\text{II.3})$$

- ✓ **Heat absorbed by THE sensor (Qabs):**

$$Q_{abs} = a \times Q_{inci} \quad (\text{II.4})$$

- ✓ **Loss thermal (Qperte):**

$$Q_{perte} = K \times H_{AS} \times (T_c - T_a) \quad (\text{II.5})$$

✓ **Heat useful (Q utile):**

$$Q_{\text{utile}} = \dot{m} \times CP \times (T_{\text{fe}} - T_{\text{fs}}) \quad (\text{II.6})$$

✓ **Efficiency of sensor (η):**

$$\eta = (Q_{\text{utile}} / Q_{\text{inci}}) \times 100\% \quad (\text{II.7})$$

A: the sensor surface area (m^2).

G: irradiation solar (w / m^2). α : the absorptivity of the sensor.

K: loss coefficient thermal sensor ($\text{W} / \text{m}^2 \cdot \text{K}$).

Ta: ambient temperature ($^{\circ}\text{C}$).

Tc: sensor temperature ($^{\circ}\text{C}$).

Tfe: temperature of fluid input.

Tfs: output fluid temperature.

η : sensor efficiency.

II.3.2 Reservoir of storage

The storage tank, also known as the hot water tank, was manufactured with a large capacity to keep the water hot throughout the day. This component consists of various elements to retain the heat:

II.3.2.1 Materials that are resistant

Generally, the tank is made of a material metallic such as steel, stainless steel or of synthetic or various materials resistant has high temperature.

Miller to study two balloons of different sizes and different materials (aluminum, glass), the results indicate that the degradation of the thermocline in the aluminum balloon is six times faster than that of the glass balloon.

Murthy et al. experimentally demonstrated the impact of the conductivity of the tank materials on stratification using two materials, aluminum and steel. The disappearance of the thermocline is more pronounced in the case of the aluminum tank.

The choice of materials is important to avoid the loss of energy but at the same time we need to improve stratification to prevent energy transfer by convection.

Tanks made from stainless steel and enameled steel dominate the market due to their strength and durability properties.

II.3.2.2 The insulation

To improve energy efficiency in the tank, it is mandatory to apply thermal insulation around the tank with insulating materials such as glass wool or polyurethane; the thickness of the insulation helps to reduce energy losses.

He east recommended of complete all the gaps around of reservoir of storage in use the insulation.

II.3.2.3 Heat exchanger thermal

The interchange thermal allows of transfer their heat of circuit primary (solar) towards the secondary circuit (water heater); this element is usually made of steel or copper.

II.3.2.4 The supplement

System energy supplementary plays A role of rescue or compliment for answer to needs of hot water he exists different fashions:

- ✓ Without appointment
- ✓ With appointment hydraulic
- ✓ With appointment electric
- ✓ With appointment hydraulic and electric

David B studied stratification in a storage tank at a uniform temperature, containing an electrical point located in the middle of the tank. The results show that the auxiliary heating element heats the area directly below the element. The energy supplied by the element is 9 kWh, while the total energy within the tank is 7.48 kWh, taking into account energy losses of approximately 17%.

II.3.2.5 Stratification In the ball of storage

The density of water changes depending on its temperature; we can say that water becomes denser when it is colder.

There stratification East A phenomenon natural separated the two levels water (hot) And (cold) in the even reservoir, there thermocline East a layer of separation between two zones.

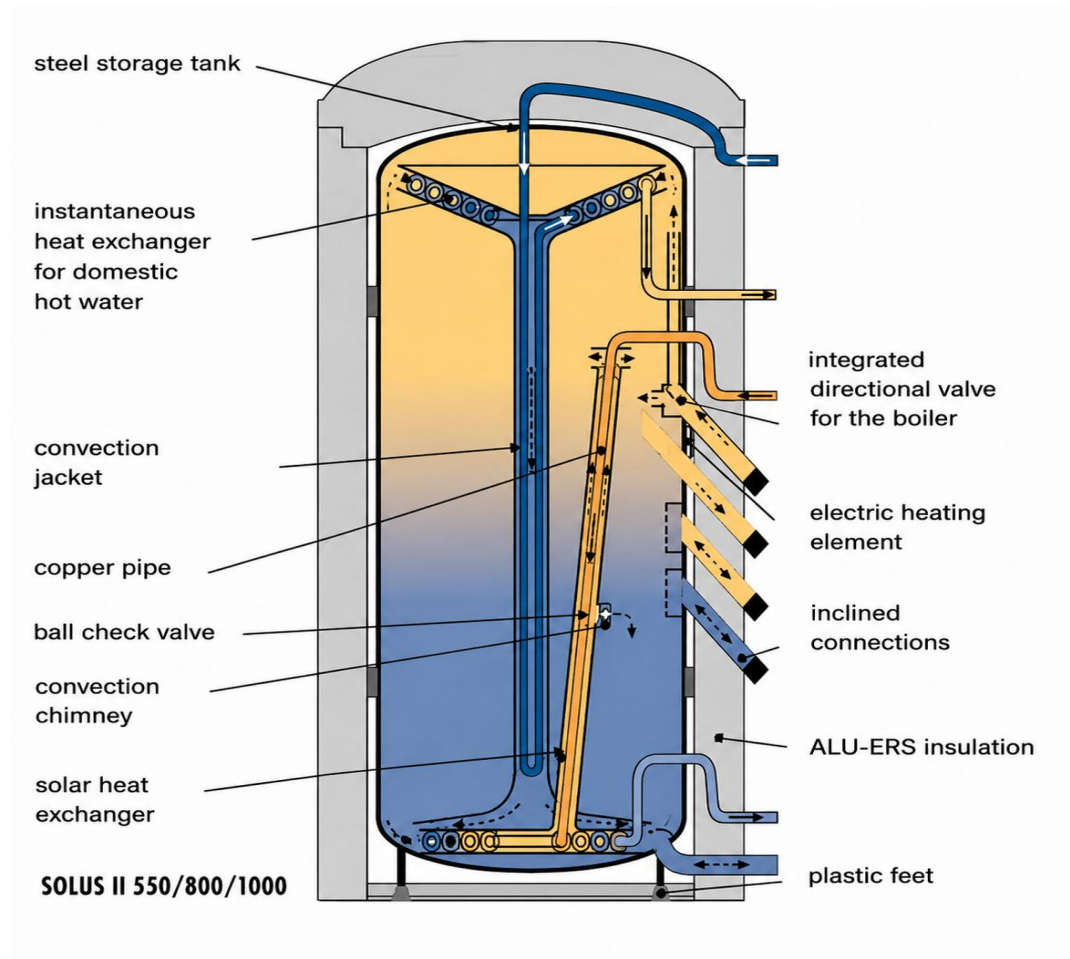


Figure II. 7: ball of stratification SOLUS

Energy balance

For represent the changes of temperature of water in the reservoir of storage, a formulation of energy balance could be employee.

$$Q = m \times cp \times \Delta T \quad (\text{II.7})$$

Q: rate of variation of the quantity of heat (W)

m: mass flow rate of fluid (kg / s)

CP: capacity water thermal ($J/kg \cdot K$)

ΔT : rate of variation of the temperature of water In THE balance sheet of storage (K / s)

II.3.3 Hydraulic circuit

The installation hydraulic guaranteed their distribution effective of water hot, She East

composed of miscellaneous elements for reach this objective:

II.3.3.1 The conduits

They are the links between the sensor and the tank. It will be subjected to more severe conditions when installed outdoors (high temperature, pressure, solar heat, etc.).

II.3.3.2 Insulation of conduits

He minimizes the losses of heat in the pipes and protected the conduits.

Insulation must be made of manner has resisted to severe conditions.



Figure II. 8: insulation of the conduits

II.3.3.3 Valve stop

Valve stop is employed for regulate and control the passage of fluid.



Figure II. 9: a valve stops

II.3.3.4 Valve of security and the manometer

the manometer measure and noted their value of pressure, there valve of security regulates and control the pressure in the circuits.



Figure II. 10: valve of safety with a pressure gauge

II.3.3.5 Vase operating

He compensated the changes of volume of fluid heat transfer fluid; he east made of materials that withstand high temperatures



Figure II. 11: vase operating

II.3.3.6 Flap backflow

Flap anti-reverse prevents their traffic reverse by thermophili son in the circuit when the system East has a temperature superior has that of the sensors. This traffic East generates cooling from accumulation.



Figure II. 12: check valve

II.3.3.7 flow meter

He supplied an indication of Speed in the circuit hydraulic. he East used for settle and

control the flow rate in the system; it is measured in liters per minute.

II.3.3.8 thermometer

He measures the temperature of THE fluid entrance and exit in THE sensor.



Figure II. 13: thermometer

II.3.3.9 Circulator

It moves the fluid through the solar collector. The circulator must be installed on the pipe back to the sensors. The choice of pump depends on two criteria: the volumetric flow rate and the manometric head.



Figure II. 14: A circulator of liquid

The fluid can be moved in the system from the sensor to the reservoir by different modes of circulation.

II.3.3.9.1 Types of traffic

II.3.3.9.1.1 One-piece solar water heater

The most basic water heaters consist of a single unit: the tank and the manifold. Solar. Domestic hot water circulates directly through the panels. Under the effect of solar radiation, the water heats up and increases in density.

The balloon is located slightly above the panel. Therefore, no pump is necessary. However, the

reservoirs water hot must be placed at edge of the panel's solar panels.

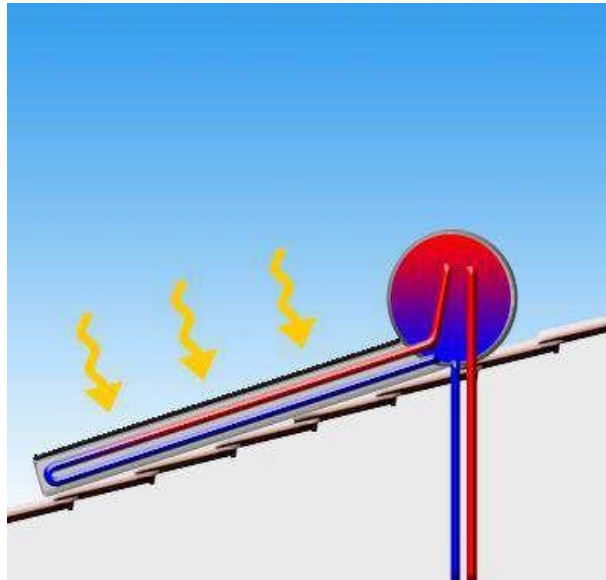


Figure II. 15 : one piece

II.3.3.9.1.2 Traffic by thermophili son (natural)

As previously mentioned, the density of water changes with its temperature; water at a lower temperature is denser. In a water heater system, cold water flows down to the bottom of the tank and into the pipes.

In a thermophilic circuit, the fluid, once heated, becomes less dense and rises to the top of the system. Subsequently, the colder (denser) fluid descends back to the bottom, ready to be heated again.

He exists two models of traffic forced:

- ✓ Horizontal: there tank of storage East placed below of the energy receiver.
- ✓ An element separated: the ball of storage East place in their House and the solar panels and always installed on the terraces.

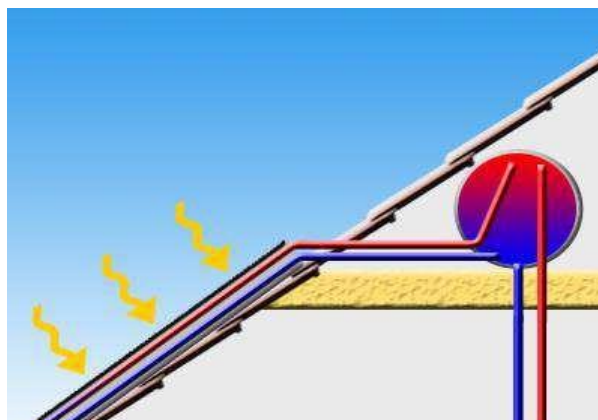


Figure II. 16: diagram of water heater separated thermophili
son

II.3.3.9.1.3 Traffic by pump (strength)

This type of circulation uses a pump that transforms electrical energy into hydraulic energy and transfers the fluid from one point to another within the solar collectors. It has two important characteristics:

- ✓ The Speed.
- ✓ There pressure.

This last provides a charge more removed that the thermophilus.



Figure II. 17: diagram of water heater traffic strength

II.3.4 Regulation and orders

A control system needed to optimize energy consumption for the system. In addition, for this purpose, the system is composed of several instruments to regulate and control the fluid temperature in the water heater.

II.3.4.1 Thermostat

The thermostat measures and controls the temperature of the solar water heating system. This component activates the electric heating element and ensures the proper functioning of the system and the maintenance of the optimal temperature.

The thermostat incorporates temperature sensors to monitor the water temperature over time. Based on this data, the thermostat operates and activates automatically the electrical resistance.

II.3.4.2 Resistance electric

Solar energy alone may not be sufficient to provide the desired hot water temperature. In this case, electrical energy is used to provide hot water throughout the day.

Their resistance electric works automatically when the thermostat detects the temperature. This solution guarantees their availability of hot water all day long.

It plays a backup role when the system is unable to provide hot water using solar energy alone.

II.3.4.3 Controller

The installation consists of an instrument of measure. It controls the change of the temperature.

The role of the controller is to enable, through appropriate control, the transfer of captured energy in cases where the temperature of the fluid in the collectors is higher than that of the tank. The controller for the proper operation of the pumps will always be of the differential type, operating according to the temperature difference between the collector outlet and the solar storage tank.



Figure II. 18: regulator

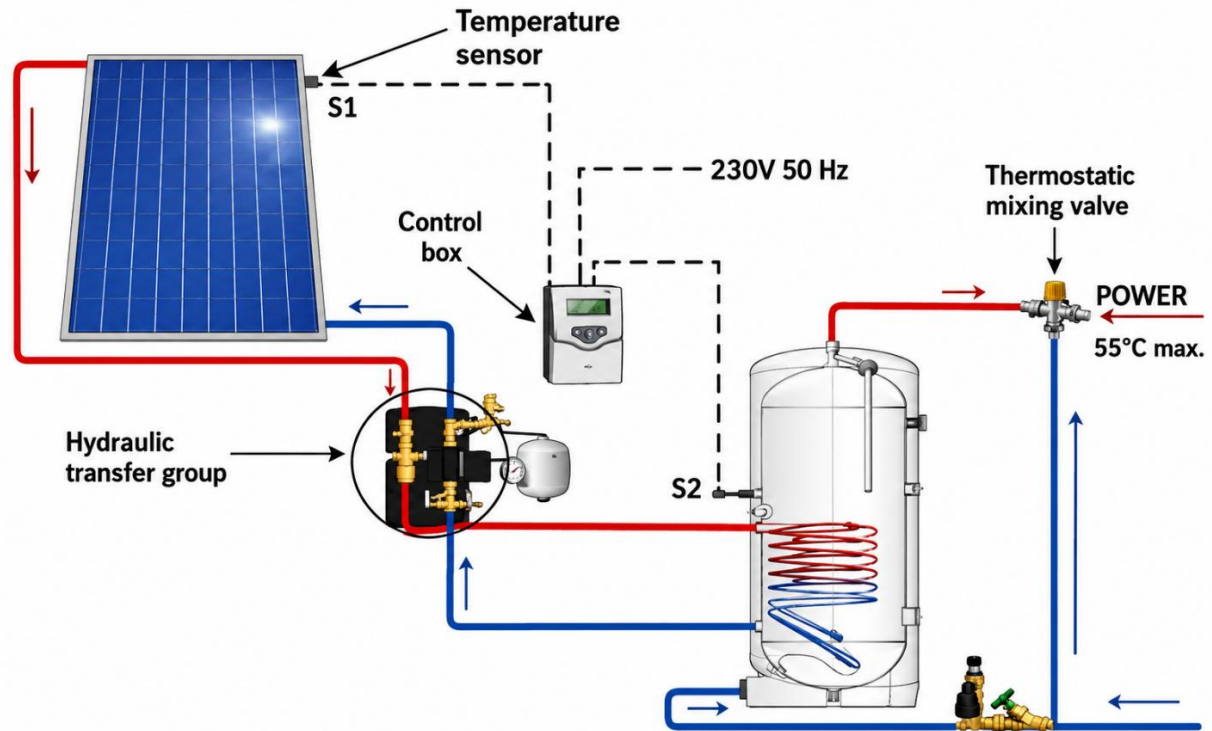


Figure II. 19: plan present the components installation water heater solar

II.4 Facility of a water heater solar

There putting in place of a water heater solar East a part essential in order to ensure the efficiency and longevity of our solar water heating system depend on careful planning and thorough consideration of the various aspects. Elements to take into consideration in order to improve the performance of our system.

II.5 Conclusion

This chapter presented the operating principles, components, and applications of solar heating systems, with particular emphasis on solar water heating technology. The study demonstrated that solar thermal systems represent an efficient and sustainable solution for producing domestic hot water and supporting space heating, especially in regions with high solar potential such as Algeria.

The analysis of the different system components—including solar collectors, storage tanks, hydraulic circuits, pumps, controllers, and auxiliary heating devices—showed that the overall performance of a solar heating installation depends on the proper integration and optimization of each element. Particular attention was given to flat-plate solar collectors due to their simplicity, reliability, and suitability for residential applications.

Chapter III: System Sizing

III.1 Introduction

In this study, the energy requirements for such a system were evaluated for a typical F3 residential building located in Laghouat, Algeria.

The heating energy demand was determined using the regulatory technical document (DTR C3.2), which used to assess the compliance of buildings with thermal regulations. Furthermore, the hot water demand for domestic use was estimated using an analytical method based on consumption patterns and climatic conditions.

III.2 Geographic localisations (Wilaya de Laghouat)

The software METEONORM (version 7.1) provides the geographical features of the site designed as such:

Longitude : 2.88° Est

Latitude : 33.80° Nord

Altitude : 750 m

The thermal classification of DTR (3-2) is relative to the communities of Algeria, the Wilaya of Laghouat, and is classed in the semi-arid climate zone (Zone B), affected by large areas, secs, and high relative volumes.

The Laghouat villa, with an environmental superficial area of 25,000 km², is located in the Hauts Plateaux region, in the center of Algérie. It takes place in a transition zone between the north and Sahara.

III.3 Climatic Characteristics

laghouat

 Radiation		 Temperature		 Precipitation		 Sunshine duration	
 Daily global radiation			 Daily temperature			 Data table	
	Gh kWh/m ²	Dh kWh/m ²	Bn kWh/m ²	Ta °C	Td °C	FF m/s	
January	115	23	211	10.4	3.3	1.4	
February	125	28	188	12.4	3.8	1.7	
March	179	42	233	14.3	5.4	2.3	
April	203	57	218	18.3	8	2.8	
May	227	72	220	23.3	11.6	2.5	
June	221	84	186	28.7	13.8	2.3	
July	221	88	182	31.9	14.9	2.1	
August	202	83	167	31.7	16.7	2	
September	177	53	195	27.2	15.8	1.8	
October	145	43	183	20.5	12.1	1.7	
November	116	23	202	14.8	7.7	1.6	
December	103	20	203	11.3	4.5	1.5	
Year	2032	614	2389	20.4	9.8	2	

Figure III. 1: Climatic Characteristics

III.4 Laghouat Climate Data

Gh: Global solar radiation on a horizontal plan

BN: Irradiation solar direct normal

Dh: Irradiation solar diffuse on a horizontal plan

Ta: Air temperature

Td : Point of rose

FF : Vitesse du vent

III.4.1 Temperatures

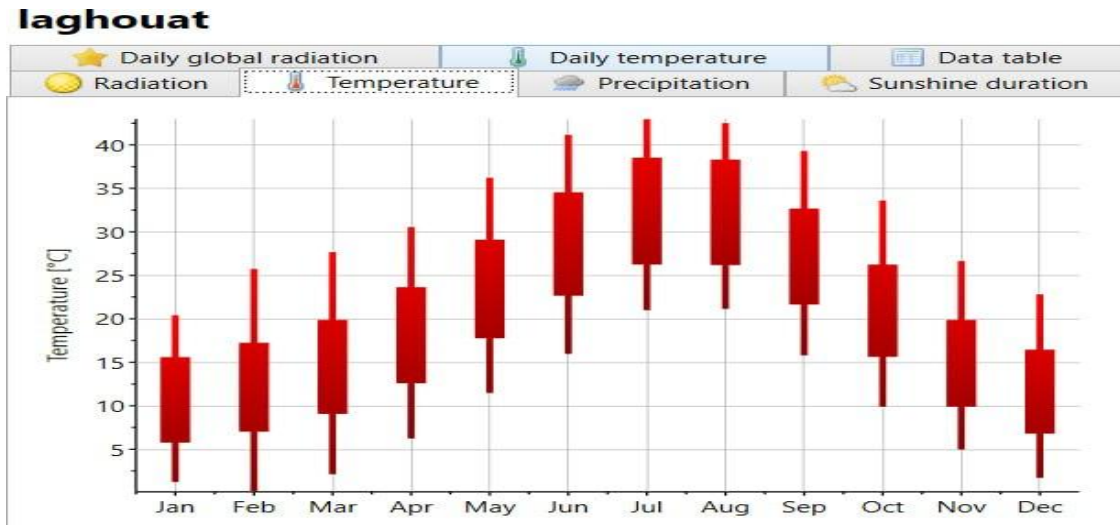


Figure III. 3: Average monthly temperatures

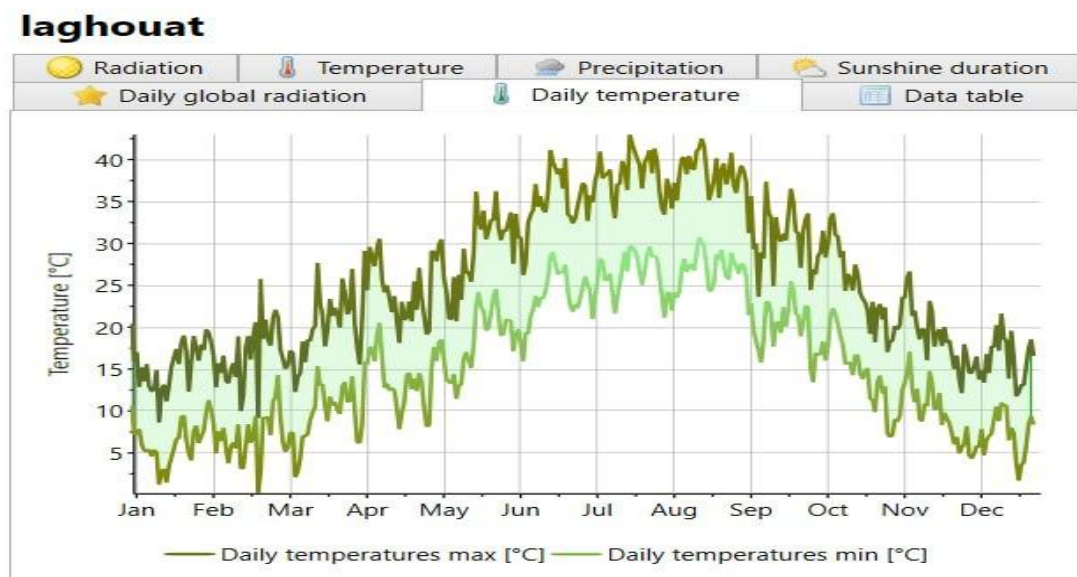


Figure III. 2: Daily temperature

The accompanying figure illustrates the monthly variations in air temperature in Laghouat, highlighting the minimum, average, and maximum values throughout the year. This distribution provides a clear understanding of the region's thermal behavior and its impact on building energy efficiency.

The temperature curve indicates that Laghouat has a semi-arid climate with significant annual temperature fluctuations. During winter (December to February), temperatures drop to relatively low levels, with minimum values ranging from approximately 2 to 5°C and maximum temperatures ranging from 15 to 20°C. These conditions lead to a significant increase in heating demand.

In contrast, summer (June to August) is characterized by significantly higher temperatures, with maximum values potentially exceeding 40°C, while minimum values remain above 20°C. These

conditions result in a substantial increase in cooling requirements and thermal discomfort if passive or active cooling strategies are not implemented.

III.4.2 Sunlight

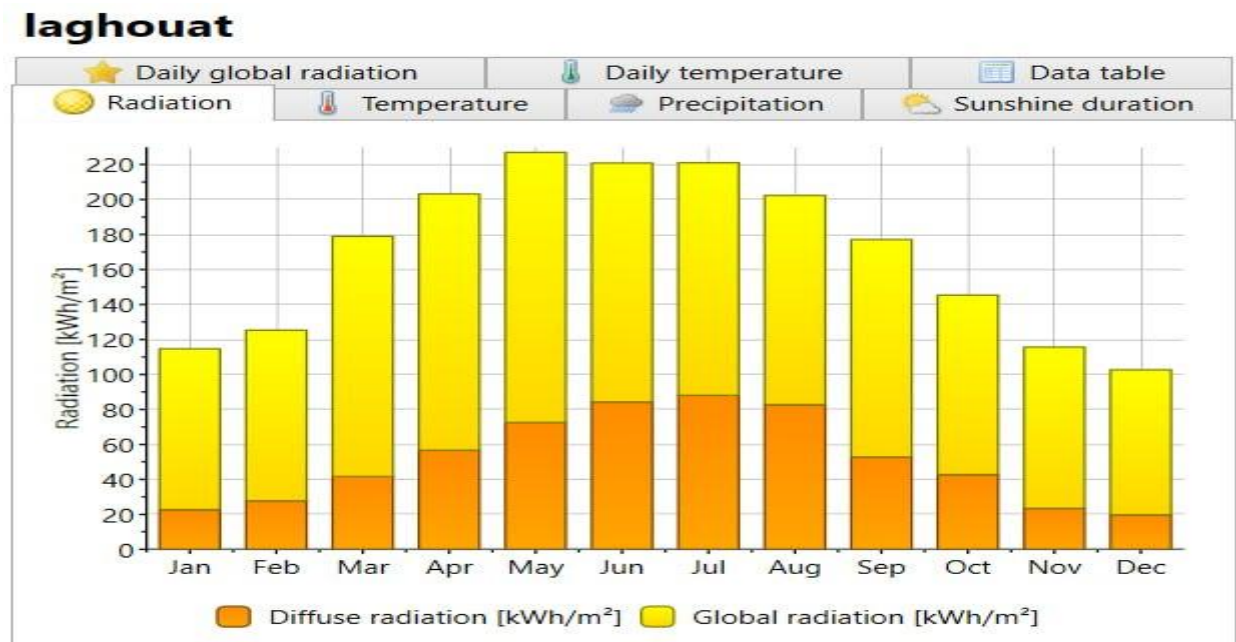


Figure III. 4: Monthly solar irradiation

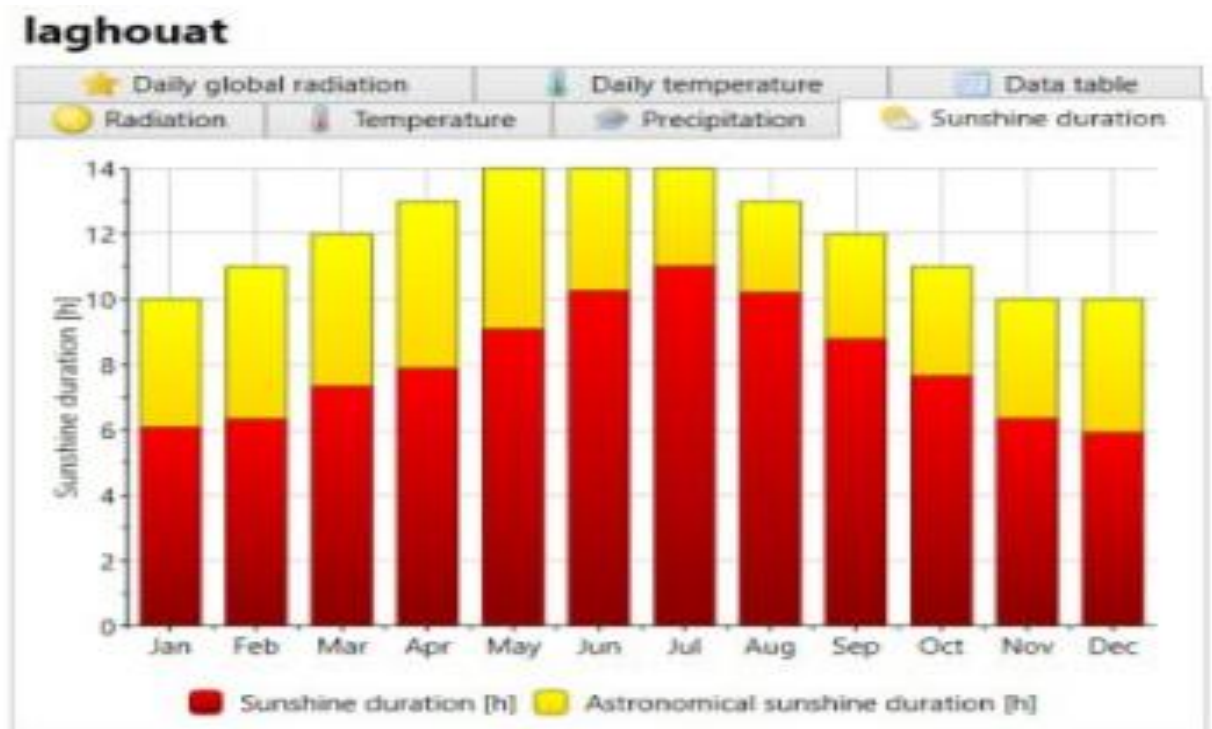


Figure III. 5: Duration of insolation.

III.4.2.1 Solar Radiation Distribution

The region is characterized by a strong global horizontal solar irradiance (GHI) distribution, peaking in May at over 220 kWh/m². Atmospheric Clarity: A significant observation is the low ratio of diffuse horizontal solar irradiance (DHI) to total global horizontal solar irradiance. This low DHI ratio indicates a high atmospheric clarity index (K_t), suggesting that the region rarely experiences heavy cloud cover. Direct Solar Radiation Potential: This clarity indicates exceptionally high direct vertical solar irradiance (DNI), making the region suitable not only for conventional photovoltaic systems but also for highly efficient concentrated solar power (CSP) technologies.

III.4.2.2 Photoperiod and Sunshine Duration

Analysis of sunshine duration highlights optimal utilization of available daylight. Operating Hours: Actual sunshine hours closely align with astronomical sunshine duration, peaking at approximately 11 hours per day in July. Seasonal stability: Even during the winter solstice (December), the region maintains approximately 6 hours of sunshine daily. The small difference between theoretical and actual sunshine hours confirms the low cloud cover in all seasons.

a) House presentation

The apartment under study is a three-room apartment (F3 type) located in the wilaya of Laghouat, specifically in the El Maamoura neighborhood.

This apartment features a classic, functional layout adapted to the needs of an average family. It comprises the following spaces:

A spacious living room for daily activities,

Two bedrooms (Bedroom 1 and Bedroom 2) ensuring the occupants' comfort,

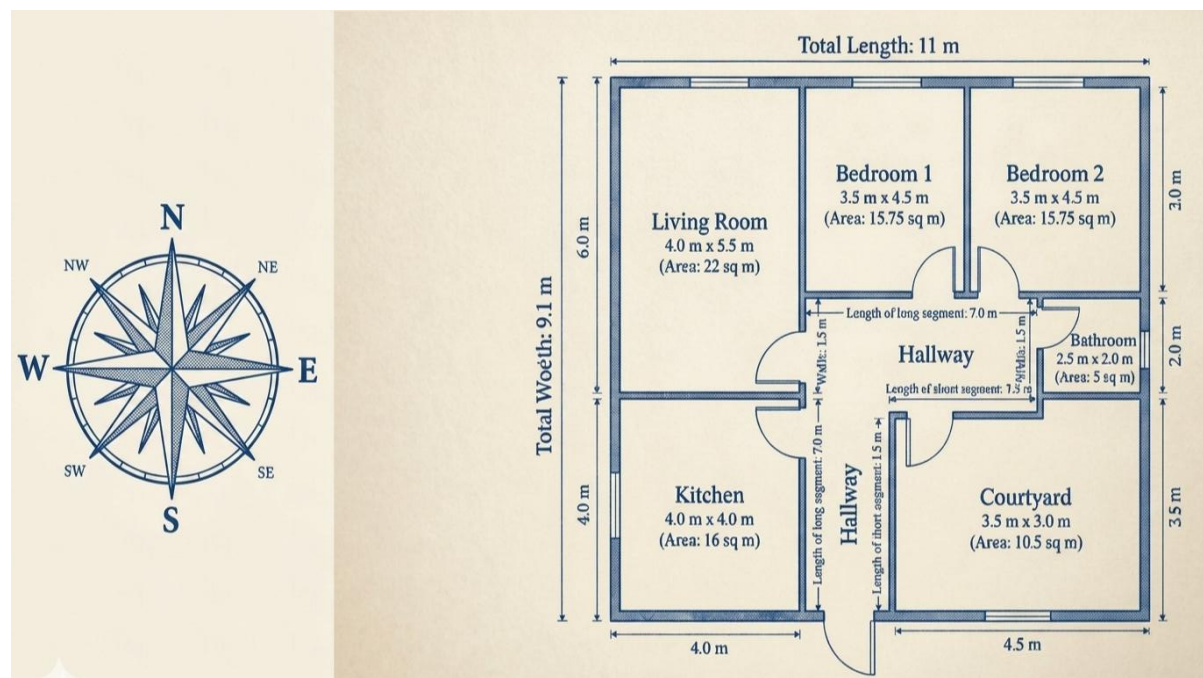


Figure III. 6: Site plan of the prototype house.

A separate kitchen, A bathroom, A hallway providing internal access, A courtyard allowing for ventilation and natural light.

The total living area is approximately 100.1 m², with a length of 11 m and a width of 9.1 m, which corresponds to a typical residential configuration in this region.

- **Architectural data of the house**

Height of the house	2,80 m
Surface of the house	100.1m ²
Volume of the house	254.8 m ³

- **Geographical data of the house**

Latitude (ϕ)	33.80°
Longitude (L)	2.88°
Altitude	750 m

➤ **Losses of their House**

THE calculation of the losses by the envelope of their House East do by their Algerian thermal regulation DTRC3.2

THE losses total D for an accommodation, are data by:

$$D = D_T + D_R$$

Or: - D_T (in (W/°C)) represents the losses by transmission,

- D_R (in (W/°C)) represents the losses by renewal of air.

➤ **Losses by transmission:**

THE losses by transmission (DT) I of a volume i are data by:

$$D_T = D_s + D_{li} + D_{sol} + D_{inc}$$

- D_s (in (W/°C)) represents the losses surface has through the parts current of the walls in contact with the outside;

- D_{li} (in (W/°C)) represents the losses has through the connections;

- D_{sol} (in (W/°C)) represents losses has through the walls in contact with the ground

- D_{inc} (in (W/°C)) represents the losses has through the walls in contact with the local

No hate.

➤ **Losses surface**

$$D_s = D_m + D_{po} + D_f + D_p + D_t$$

D_m : Loss by the wall outside

D_{po} : Heat loss through doors

D_f : Losses by the windows

D_p : Heat loss through the floor

D_t : Heat loss through the roof

III.4.3 Thermal Resistance of Exterior Wall

III.4.3.1 Formula

Table: Exterior Wall

Layer	Thickness e (m)	λ (W/m·K)	R (m²·K/W)
External mortar	0.02	1.15	0.017
Hollow brick	0.20	0.84	0.238
Internal plaster	0.02	0.70	0.029
Total layers	—	—	0.284
(R _{si})	—	—	0.13
(R _{se})	—	—	0.04
Total (R_{wall})	—	—	0.454 m²·K/W

III.4.3.1.1 Thermal Resistance of Roof (Toiture of Roof)

Table: Roof

Layer	Thickness (m)	λ	R
Waterproof layer	0.02	1.15	0.017
Concrete slab	0.20	2.0	0.10
Internal plaster	0.02	0.70	0.029
Total layers	—	—	0.146
(R _{si})	—	—	0.10
(R _{se})	—	—	0.04
Total (R _{roof})	—	—	0.286 m ² ·K/W

III.4.3.1.2 Thermal Resistance of Floor (Plancher Bas)

Table: Floor

Layer	Thickness (m)	λ	R
Internal plaster	0.02	0.70	0.029
Concrete slab	0.20	2.0	0.10
Plaster	0.02	0.70	0.029
Total layers	—	—	0.158
(R _{si})	—	—	0.17
(R _{se})	—	—	0.04
Total (R _{floor})	—	—	0.368 m ² ·K/W

- Exact Areas from Your Plan

Element	Area (m ²)
Exterior walls	95.56
Roof	100.1
Floor	100.1
Windows	11

- Heat Losses by Transmission

Formulation

$$D=U \cdot S \cdot \Delta T$$

With $U= 1/R$

Heat Loss the wall outside

Parameter	Value
(R)	0.454
(U)	2.20
Area (S)	95.56 m ²
(\Delta T)	15°C
Loss ($D_{\{walls\}}$)	3153 W

- Heat Loss through Roof

Parameter	Value
(R)	0.286
(U)	3.50

Parameter	Value
Area (S)	100.1 m ²
(\Delta T)	15°C
Loss (D_{roof})	5255 W

- Heat Loss through Floor

Parameter	Value
(R)	0.368
(U)	2.72
Area (S)	100.1 m ²
(\Delta T)	15°C
Loss (D_{floor})	4084 W

- Heat Loss through Windows

Parameter	Value
(U)	5.8
Area (S)	11 m ²
(\Delta T)	15°C
Loss (D_{windows})	957 W

- Total Heat Loss

Element	Loss (W)
Walls	3153
Roof	5255
Floor	4084
Windows	957
Total (D _T)	13,449 W ≈ 13.45 kW

III.4 Conclusion

This chapter focused on the sizing and evaluation of the thermal requirements of a typical F3 residential building located in the wilaya of Laghouat, Algeria. The study began with the presentation of the geographical and climatic characteristics of the region using Metronome data, highlighting the high solar potential and the semi-arid climate conditions that strongly influence the building's energy demand.

Chapter IV: Simulation with TRNSYS

IV.1 Introduction

In this study, we will carry out a thermal simulation of a prototype solar water heater (forced circulation) for a site located in Laghouat, using the TRNSYS dynamic simulation software. We will simulate the domestic hot water requirements using data obtained from our analytical calculations, utilising solar energy as the heat source.

IV.2 Simulation with TRNSYS

IV.2.1 Introduction to the TRNSYS software

TRNSYS is a dynamic simulation software developed by the CSTB (Scientific and Technical Centre for Building) in 1975 as part of an international collaboration. This software enables the behaviour of a complex system to be simulated. It was the forerunner of many other simulation software packages, which use its generic solver and/or some of its models (Energy Plus, Energy 10, CASIS, etc.).

TRNSYS is based on a block-diagram approach. This modular approach makes it possible both to break down complex problems into several less complex ones and to work in an ‘open’ environment, allowing new components and concepts to be added. A TRNSYS simulation project therefore involves selecting a set of mathematical models of physical components (either by using existing models from the TRNSYS model libraries or by creating them) and describing the interactions between these models.

TRNSYS 16 contains a large number of standard models (Utility Systems, Thermal Storage, Equipment, Loads and Structures, Heat Exchangers, Hydraulics, Controllers, Electrical/Photovoltaic Components, Solar Collectors, etc.). Simply link them together in a project editor to define a simulation project. Several TRNSYS model libraries are also available as additional commercial products, developed by specialist engineering firms. There are several building models. The most comprehensive model allows for a highly detailed simulation of the thermal behaviors of a multi-zone building (room temperature, energy requirements, air humidity for each zone and each surface; gains from infiltration/ventilation, convective coupling with other zones; sensible energy variation; latent energy requirements; solar energy entering through windows; comfort; ...).

TRNSYS Studio will be used to link TRNSYS with the schematic diagram of the project to be modelled (see Figure VI.1). Its main task will be to solve the set of equations under the given conditions, primarily the time dimension (initial/final time steps).

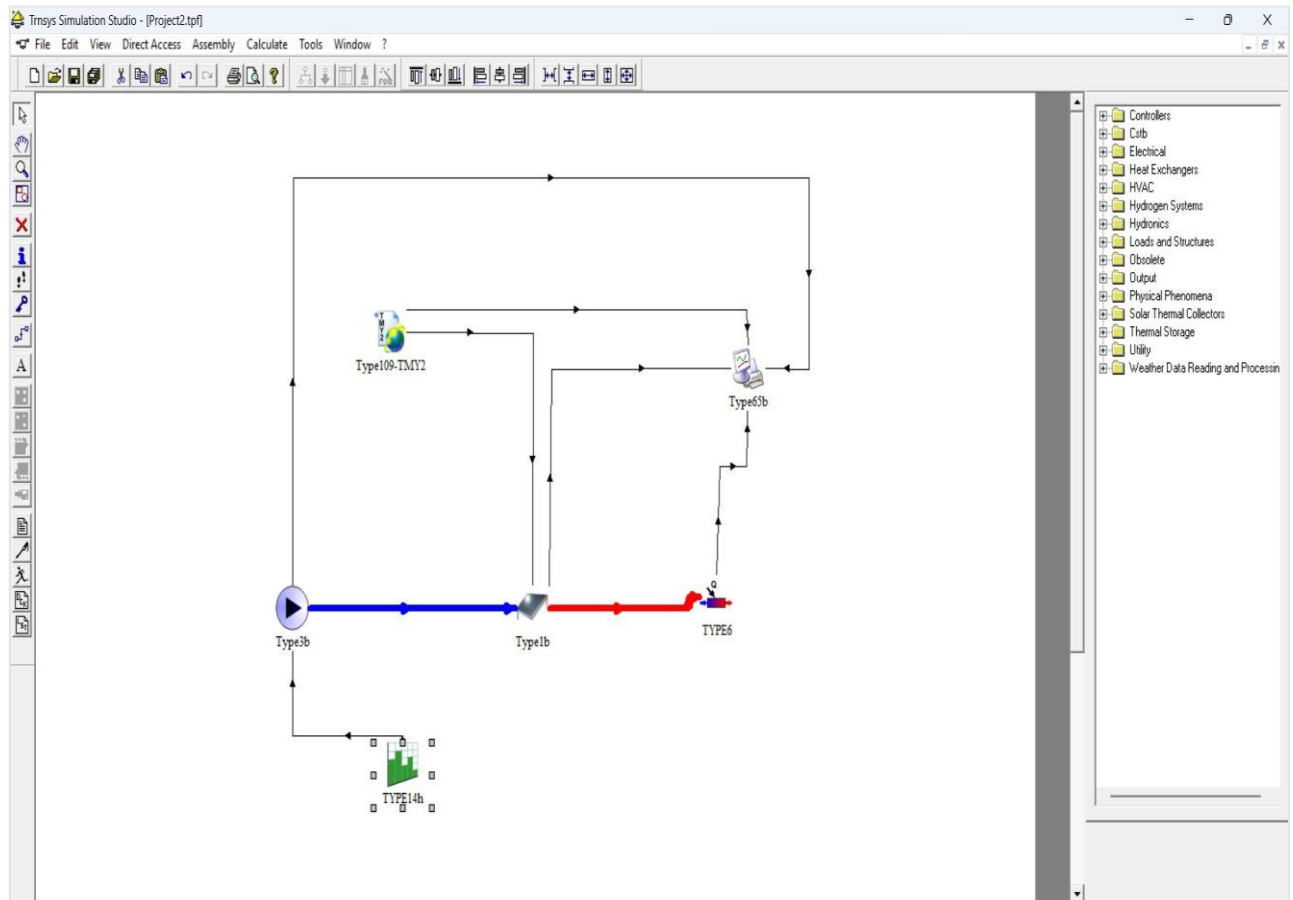


Figure IV. 1: TRNSYS operational diagram

IV.2.2 TRNSYS environment

Unlike the vast majority of other simulation software, TRNSYS is not solely focused on evaluating the performance of thermal and electrical energy systems. It can also be used to model other types of dynamic systems, such as traffic flows or biological processes.

IV.2.3 TRNSYS tools

Many software packages have been enhanced so that they can be integrated with TRNSYS, thereby providing additional functionality or data.

- Meteornorm provides reliable climate data from over 8,000 stations located around the world.
- SIMCAD, a CAD software package for capturing building structures and construction materials. While operating within a CAD environment, it allows users to create objects by assigning specific attributes (thickness, materials used, etc.). Once the project is complete, it can be exported as a building description file readable by TRNSYS, whilst simultaneously generating quantity take-off tables in Excel format, providing details on object data (surfaces, volumes, materials, etc.).
- EES (Engineering Equation Solver) is a software package designed to solve equations using various modules. It can be used alongside TRNSYS to solve a wide range of sub-problems using its solver. It is primarily used in the following disciplines: thermodynamics, fluid mechanics, heat transfer and chemistry. A wealth of data relating to these disciplines is built into the software.

IV.2.4 Applications

TRNSYS does not merely study the thermal behavior of a building; it also enables the solving of numerous systems of equations, performs dynamic simulations and allows for the creation of new models and their integration into the existing library. There are numerous advantages associated with it: multi-zone solving, system coupling, and the ability to use external resources. A wide range of data can be also taken into account, such as DHW consumption, residents' occupancy times, electricity and gas consumption, and their associated tariffs.

IV.2.5 Definition of Outputs

In Simulation Studio, the desired outputs (results) were defined; these results will be displayed in graphs and tables that can be utilized.

The specified outputs are temperatures, heating, and cooling requirements for different areas of the home. If you double-click on a link between two components, a new window will open listing all the input-output connections within that link. Figure VI.2 shows the link between the weather file (type 109) and the solar sensor (type 1b).

Variable	Value
Ambient temperature	20.0
relative humidity	100.0
wind velocity	Ambient temperature
wind direction	Incident radiation
Atmospheric pressure	Total horizontal radiation
userdefined data 2	Horizontal diffuse radiation
userdefined data 3	Ground reflectance
userdefined data 4	Incidence angle
extraterrestrial radiation on horizontal	Collector slope
solar zenith angle	
solar azimuth angle	
total radiation on horizontal	
beam radiation on horizontal	
sky diffuse radiation on horizontal	
ground reflected diffuse radiation on horizontal	
angle of incidence on horizontal surface	
slope of horizontal surface	
total radiation on tilted surface	
beam radiation on tilted surface	
sky diffuse radiation on tilted surface	
ground reflected diffuse radiation on tilted surface	
angle of incidence for tilted surface	
slope of tilted surface	

Figure IV. 2: Definition of outputs

IV.3 Modelling and simulation

IV.3.1 Meteonorm

The Meteonorm software used to provide TRNSYS with reliable hourly meteorological data for an entire year. In the absence of a nearby weather station, Meteonorm generates climatic data for a specific location through interpolation between data collected from surrounding meteorological stations.

The climatic data used for the study site are as follows:

- **Location:** Laghouat, Algeria
- **Latitude:** 33.80° N
- **Longitude:** 2.88° E
- **Altitude:** 750 m

The weather database corresponds to the year 2020 for both temperature and solar radiation parameters. Meteonorm calculates the climatic conditions of the selected site by applying interpolation techniques based on data from neighboring weather stations, ensuring accurate and representative meteorological inputs for TRNSYS simulations.

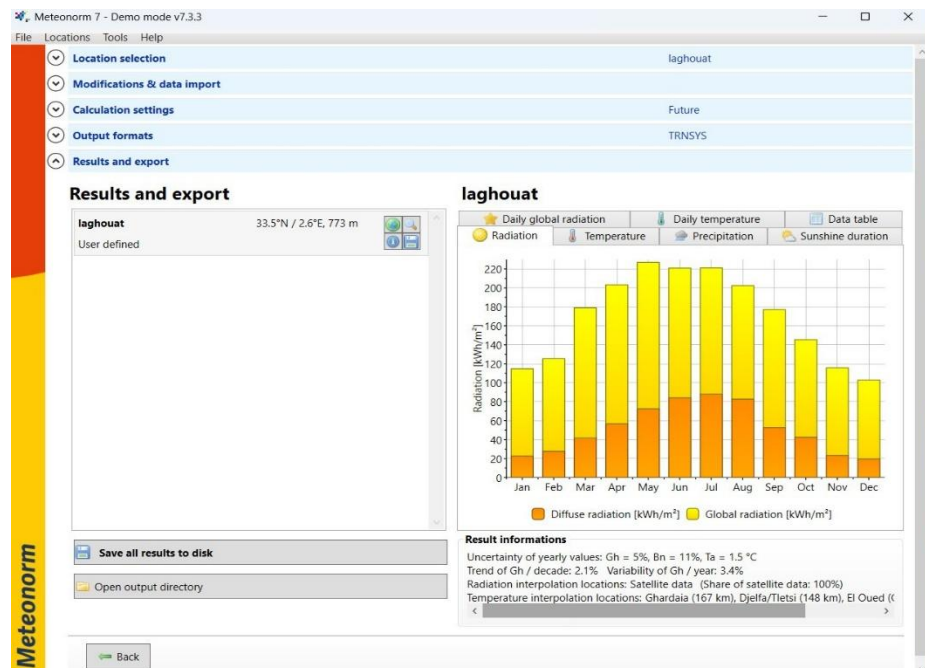


Figure IV. 3: Meteonorm software interface

IV.3.2 Presentation of the installation model

Once the data required for modelling has been collected, it is essential to select the appropriate components from the various libraries available. As can be seen in Figure (VI.4), within the TRNSYS software, we will now outline the various components of this solar system model, which comprises solar collectors, a pump and an auxiliary heater. We must also read and process the meteorological data for the Laghouat site and produce results (both as a plot and in a printed file). The components used are:

- Meteonorm: (Type 109-TMY2)
- pump (Type 3b),
- Results display (Type 65b)
- storage tank (Type 6),
- Flat-plate solar panel (Type 1b)
- Forcing function Type 14h

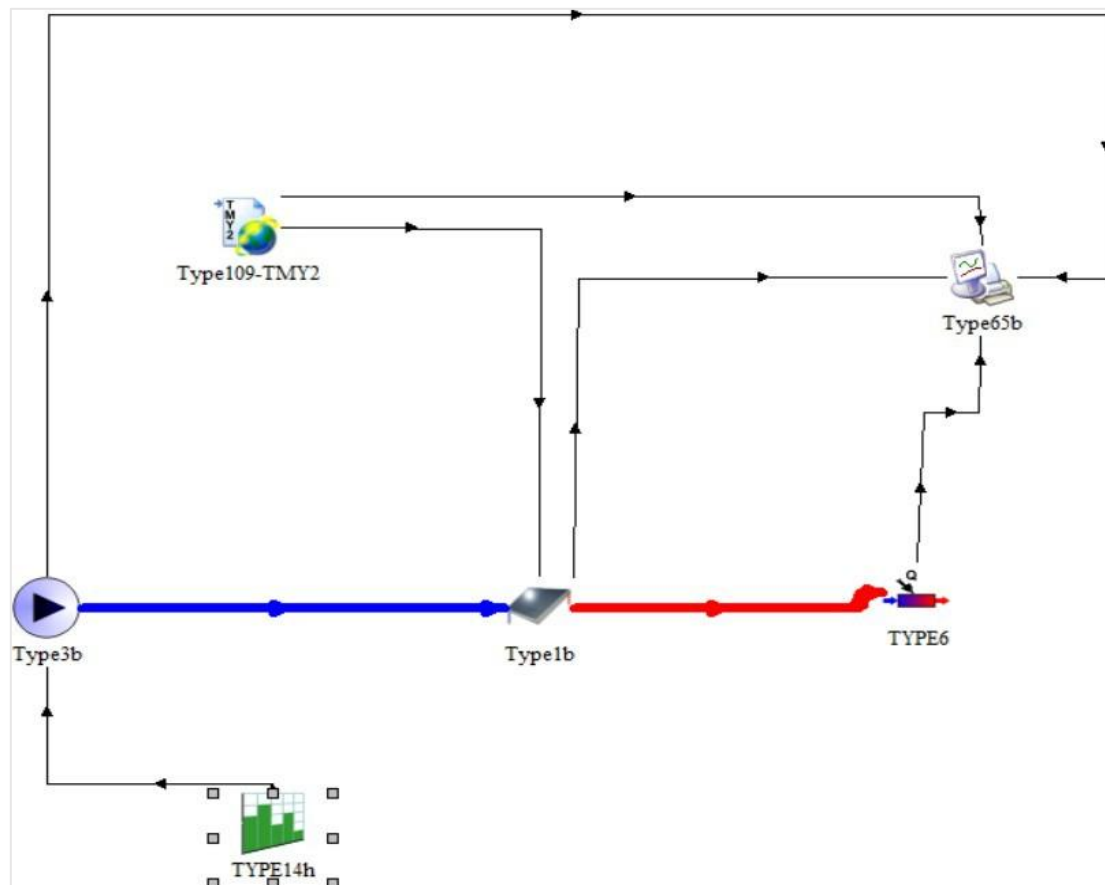


Figure IV. 4: Modelling using TRNSYS software

IV.3.2.1 Description of the various components of this system [29]

1. Type 109-TMY2

Enabling the simulation of weather conditions in a specific city and the resulting solar radiation on the sensors based on their orientation and tilt.

2. Type 3b: pump

Simple pump model (fixed flow rate).

3. Type 1: Flat-plate collector (quadratic efficiency)

This component models the thermal performance of a variety of collector types using theoretical principles.

4. Type 6: Auxiliary heating

An auxiliary heater modelled to raise the temperature of a flow using either internal control, external control or a combination of both. The heater is designed to add heat to the flow at a flow rate less than or equal to Q_{max} , which is a user-defined quantity.

5. Type 65b: In-line tracer

The online graph component used to display specified system variables at defined time intervals during the simulation. Use of this component is strongly recommended; it is widely used as it provides valuable information on the variables and allows users to see immediately if the system is not behaving as expected (visualization object with file logging and unit definition).

6. Type 14h: Time-dependent forcing function

In a transient simulation, it is sometimes useful to employ a time-dependent forcing function whose behavior is characterized by a repeating pattern. The purpose of this routine is to provide a means of generating a forcing function of this type.

IV.3.2.2 Added components and configuration

a) Reading and processing meteorological data

We will start with the data reader and solar radiation processor, Type 109. You can find it in the direct access tool (tree view in a docked window on the right-hand side of the screen). Type 109 is located under "Reading and processing meteorological data". We need to read the meteorological data for Laghouat (Algeria, Africa), which is available as part of the meteorological database generated with Meteonorm. Meteonorm files use the TMY2 data format, so we will select the template for Type 109 found under: Standard Format \ TMY2. You can add component to the project by dragging its icon from the quick access tool to the project window (see Figure VI.5).

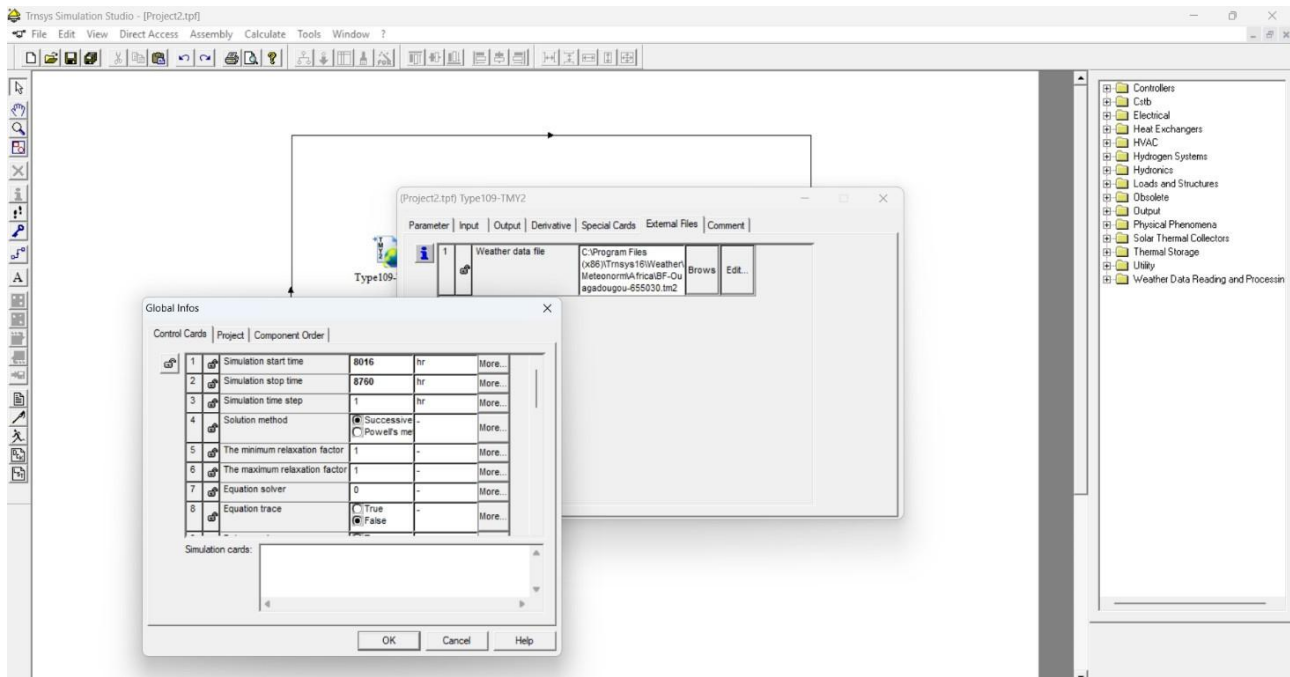


Figure IV. 5: Control cards and Type 109 (Weather data reader / processor)

b) Solar system:

We will now add the three components required for the physical system model: pump, solar collector and auxiliary heater. The selected components are:

1-Hydraulics \ Pump \ Single speed \ Type3b

- Changes to the default configuration: set the maximum flow rate (parameter 1) to 50 kg/h

2-HVAC \ Auxiliary heaters \ Type6

- Changes to the default configuration: set the maximum power (parameter 1) to 5040 kJ/h = 1400 W

3-Solar thermal collectors \ Quadratic efficiency collector \ 2nd order incidence angle Modifiers \ Type1b

c) Utility components:

We need to control the flow rate of the pump by sending a time-varying control signal, and we also need to integrate, plot and print the results. We will add 4 components:

1-Utility \ Forcing Functions \ General \ Type14h

- The default configuration will include inputs from the start to the end of the simulation. We need to change the input tab to have two inputs. This automatically updates the number of outputs.

2-Output \ Online Plotter \ Online Plotter without file \ Type65b

Parameters: we will plot 3 variables on the left axis and 2 on the right axis. By setting the axis limits to [-100; 100] for the left (temperatures) and [0; 10000] for the right (heat transfer rate)

IV.4 Conclusion

The TRNSYS calculation tool is suitable for simulating domestic hot water production processes and is used to validate our model, by integrating the site's climate data (METEONORM) and the data from our calculations. Subsequently, the results obtained by the two methods are presented, analysed and interpreted

Chapter V: Results and Interpretation

V.1. Introduction

Laghouat is a region characterized by a high solar potential and a semi-arid climate. In such a context, a solar thermal system can exploit abundant irradiation for most of the year, while the auxiliary heater can compensate for periods during which useful solar gain becomes temporarily insufficient. The purpose of this chapter is therefore to connect climatic availability, building demand, and simulated system response in a single technical interpretation.

V.2. Meteonorm data

The climatic data used for the study correspond to the city of Laghouat, located at latitude 33.80° N, longitude 2.88° E, and an altitude of approximately 750 m. According to the project document, the site belongs to the semi-arid Algerian climatic zone and benefits from a very favorable solar regime, with annual sunshine duration between about 2,000 and 3,900 hours. Such conditions make the site particularly attractive for solar thermal exploitation.

The Meteonorm radiation profile shows that global solar irradiation remains high during the entire year. Monthly global radiation is approximately 103–116 kWh/m² in winter, increases rapidly in spring, and reaches its highest values in late spring and summer, with a peak of about 225–230 kWh/m² in May and values still close to 220 kWh/m² in June and July. Even during the colder season, the available irradiation remains significant, which indicates that the reduction in solar contribution during winter caused more by thermal demand and lower ambient temperature than by a complete absence of solar resource.

laghouat

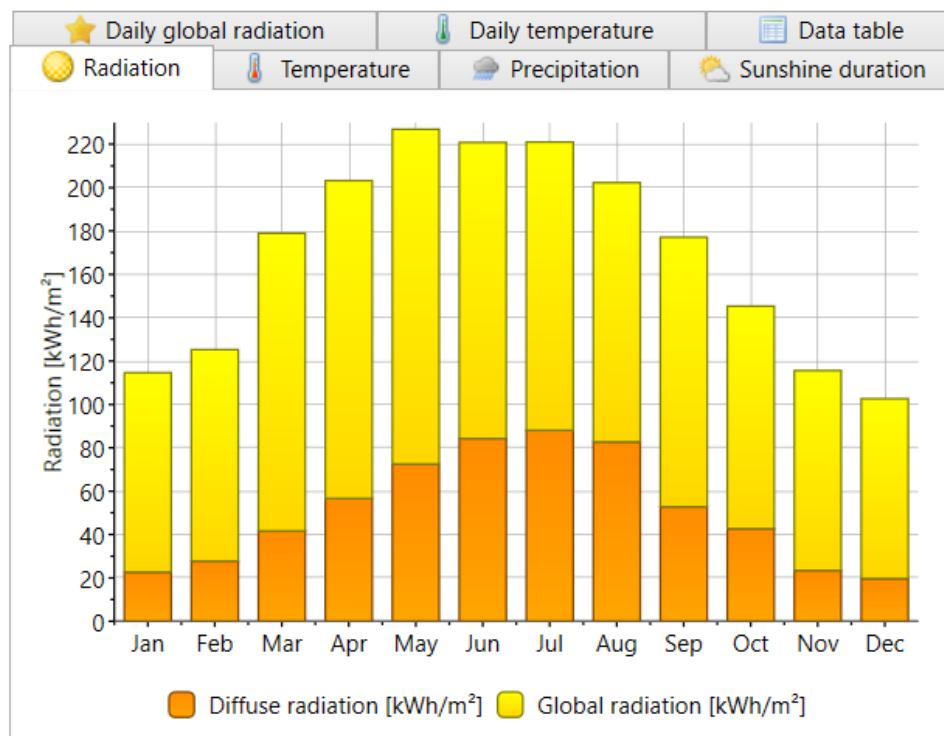


Figure V. 1: Monthly global and diffuse solar radiation in Laghouat (Meteonorm figure provided by the user).

The monthly temperature distribution confirms the strong seasonality of the site. Typical winter conditions extend from about 6–16°C in January to 7–16°C in December, while the hot season is marked by typical temperatures of about 23–35°C in June and 26–39°C in July and August. Maximum temperatures may exceed 40°C in summer, whereas winter minima can approach 0–2°C. Consequently, the heating requirement is mainly concentrated in winter nights and cold mornings, while summer operation dominated by very favorable solar collection conditions.

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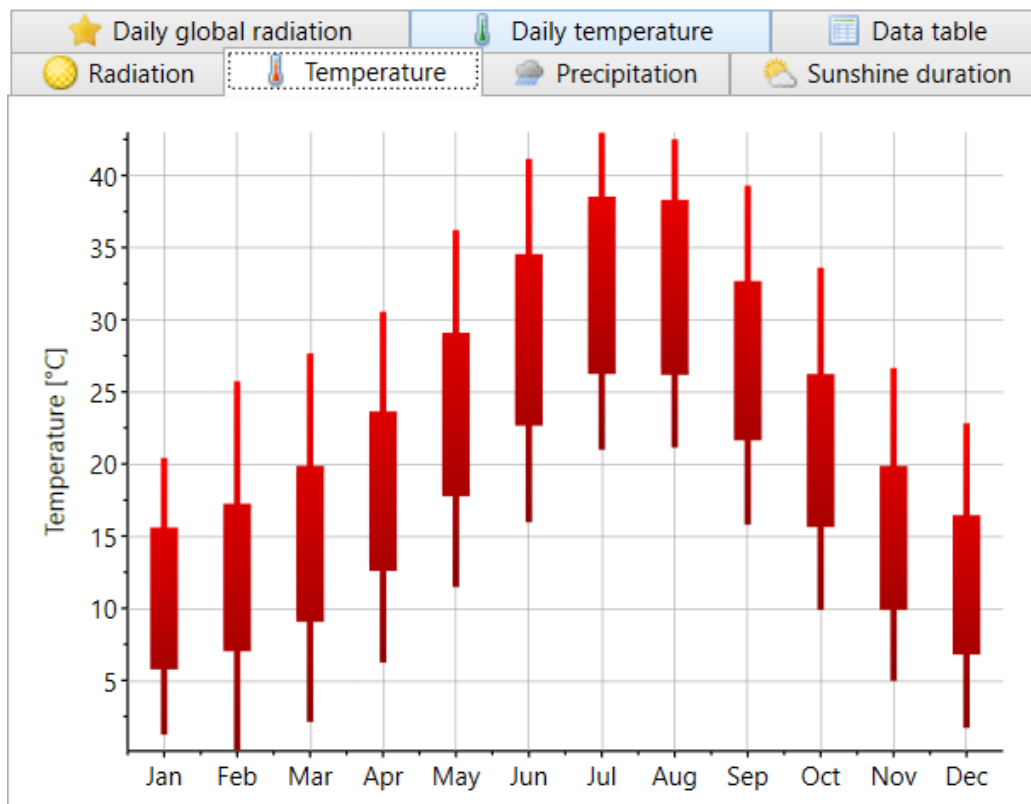


Figure V. 2: Monthly temperature distribution in Laghouat (Meteonorm figure provided by the user).

The daily minimum and maximum temperature curves reinforce this interpretation. Maximum daily temperatures rise progressively from around 15–17°C in winter to approximately 39–42°C in mid-summer, while minimum daily temperatures range from about 4–7°C in winter to 24–27°C in summer. The large difference between daily maxima and minima reflects a marked diurnal thermal amplitude, which is common in semi-arid and desert-edge regions. From an energy point of view, this means that heating demand remains relevant during the cold season, but solar collection can still be effective during daylight hours because sky clarity and irradiation levels remain high.

laghouat

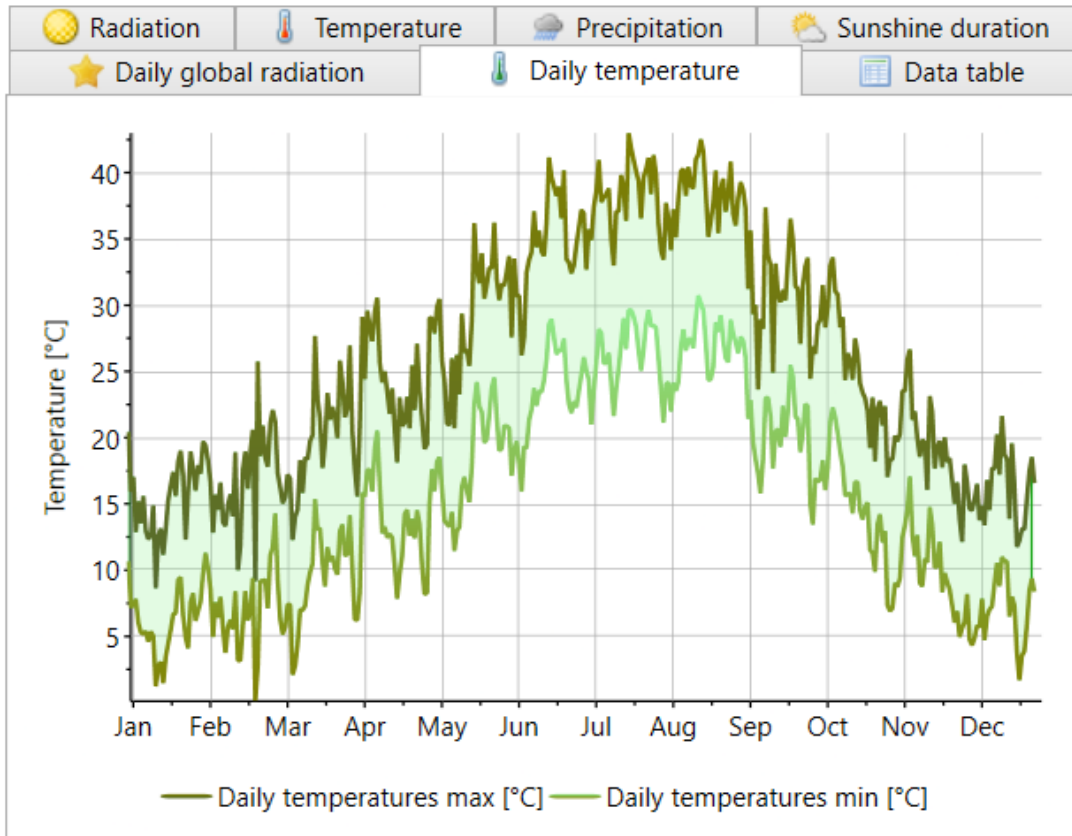


Figure V. 3: Evolution of daily maximum and minimum temperatures in Laghouat (Meteonorm figure provided by the user).

V.3. Calculation of heating and domestic hot water requirements

The sizing study concerns an F3 residential building with an area of 100.1 m² and an internal volume of approximately 254.8 m³. The thermal-loss calculation follows the Algerian regulation DTR C3.2 and considers the transmission losses through the opaque envelope and glazed surfaces. The project extract gives a temperature difference of 15°C for the heat-loss estimation and details the thermal resistance of walls, roof, and floor assemblies.

V.3.1. Verification and reference heat losses

The calculated heat losses reveal that the roof is the dominant source of thermal loss, followed by the floor, external walls, and windows. The values extracted from the project are 5,255 W for the roof, 4,084 W for the floor, 3,153 W for the external walls, and 957 W for the windows. The total transmission heat loss is therefore 13,449 W, or approximately 13.45 kW. This value constitutes the reference-heating requirement used to assess the capacity of the proposed solar-assisted system.

Element	Heat loss (W)
Roof	5,255
Floor	4,084
External walls	3,153
Windows	957
Total	13,449

V.3.2. Calculation of heating capacity

The design heating capacity derived from the building envelope is thus close to 13.45 kW. In practice, this value represents the load that the building may require under reference winter conditions. In the simulated solar configuration, the auxiliary heater is not intended to replace the entire useful solar contribution but to guarantee service continuity when the collector outlet temperature becomes insufficient. The TRNSYS model uses an auxiliary unit with a maximum power of 5,040 kJ/h, corresponding to approximately 1.4 kW, and a pump flow rate of 50 kg/h. This confirms that the system is designed as a solar-assisted installation where solar gain remains the primary driver and the auxiliary unit plays a complementary role.

V.3.3. The system's collector area and meeting requirements

The project establishes the collector area as the key design variable linking available irradiation to useful thermal production. The analytical framework is based on the collector efficiency equation and the useful heat expression, while the final performance is validated dynamically in TRNSYS. Although the exact final collector area is not explicitly readable in the provided extract, the simulation outputs clearly show that the collector repeatedly reaches high operating levels during solar-active periods. This indicates that the selected collector field is thermally responsive and capable of producing significant useful heat under Laghouat conditions.

From an interpretation standpoint, meeting the requirements does not mean that solar energy covers the demand at every hour of the year; rather, it means that the solar subsystem supplies an important share of the useful heat whenever radiation conditions are favorable, while the auxiliary heater covers transient deficits. Given the high irradiation from spring to autumn and the still appreciable winter solar resource, the proposed design is consistent with a strategy of strong annual solar contribution combined with controlled auxiliary support during colder or low-sun periods.

V.3.4. Corrected calculation page

The following page consolidates the corrected calculations for the heating requirements and the domestic hot water requirements using the numerical values provided by the user for this dwelling configuration. It is intended as a verification page to complement the analytical development presented earlier in the chapter.

Using the stated areas and transmission coefficients, namely an external wall area of 95.2 m², an external window area of 12 m², an external door area of 3 m²

$$K_m = 1.13 \text{ W/m}^2\cdot\text{K},$$

$$K_{po} = 3.5 \text{ W/m}^2\cdot\text{K},$$

$$K_f = 2.9 \text{ W/m}^2\cdot\text{K},$$

The direct substitution into the surface-loss expression gives

$$D_s = (1.13 \times 95.2) + (3.5 \times 12) + (2.9 \times 3) = 107.58 + 42.00 + 8.70 = 158.28 \text{ W/}^\circ\text{C}.$$

Therefore, the arithmetic result based strictly on the stated data is 158.28 W/°C.

However, if the adopted thesis value $D_s = 152.87 \text{ W/}^\circ\text{C}$ is retained from the original worksheet or regulation-based method, then adding the thermal-bridge losses $D_{li} = 30.58 \text{ W/}^\circ\text{C}$ leads to a total transmission loss coefficient $D_T = D_s + D_{li} = 152.87 + 30.58 = 183.45 \text{ W/}^\circ\text{C}$, rounded to 183.46 W/°C. With the reference value $D_{réf} = 604.56 \text{ W/}^\circ\text{C}$ and the air-renewal losses $D_R = 69.46 \text{ W/}^\circ\text{C}$, the regulatory verification becomes $183.46 \leq 604.56$, which confirms compliance with the reference criterion.

Verified quantity	Expression	Result
Surface heat losses	$(1.13 \times 95.2) + (3.5 \times 12) +$	158.28
Adopted thesis surface	Given value	152.87
Thermal bridge losses	Given value	30.58 W/°C
Total transmission	$152.87 + 30.58$	183.46
Reference losses	Given value	604.56
Air renewal losses	Given value	69.46 W/°C

For the heating power, the design temperatures are

$$T_{bi} = 20^{\circ}\text{C and}$$

$$T_{be} = -2^{\circ}\text{C, hence}$$

$$\Delta T = 22^{\circ}\text{C.}$$

If the correction factor 1.1 is applied to both the transmission and air-renewal terms, the corrected expression becomes

$$Q = 22 \times [(1.1 \times 183.46) + (1.1 \times 69.46)] = 22 \times (201.806 + 76.406) = 22 \times 278.212 = 6120.66 \text{ W.}$$

This is the mathematically corrected result corresponding to the written formula.

The previously reported value 5967.85 W is obtained only if the factor 1.1 is applied to the transmission term and not to the air-renewal term. Therefore, to remain strictly consistent with the displayed formula, the corrected heating power retained on this page is $Q = 6120.66 \text{ W}$.

Heating power item	Value
Indoor temperature	20 °C
Outdoor temperature	-2 °C
Temperature difference	22 °C
Corrected heating power	6120.66 W

For domestic hot water, the corrected calculation is

$$Q_{ESC} = 1 \times 4200 \times (250/24) \times (50 - 10) = 1,750,000 \text{ J/h.}$$

This corresponds to:

$$4.2 \times 10^7 \text{ J/day, or } 11.67 \text{ kWh/day.}$$

For a 31-day month, the energy demand becomes 361.67 kWh/month.

Converting the hourly energy rate into watts gives

$$Q_{ESC} = 1,750,000 / 3600 = 486.11 \text{ W.}$$

The corrected thermal-power equivalent is therefore 486.11 W.

Domestic hot water item	Result
Hourly energy	1.75×10^6 J/h
Daily energy	4.2×10^7 J/day
Daily demand	11.67 kWh/day
Monthly demand (31 days)	361.67
Corrected thermal power	486.11 W

The collector area relation is maintained in symbolic form on this correction page because the final useful solar productivity (PSU) and the adopted combined annual heating and domestic hot water need were not fully specified in the visible extract. The retained expression is $S_{ca} = 0.6 \times (\text{Heating need} + \text{DHW need}) / \text{PSU}$. Once PSU is fixed, the collector area can be obtained directly in square metres.

V.4. Results of the TRNSYS simulation

The TRNSYS simulation uses a modular configuration including the Meteonorm weather reader, a flat-plate solar collector, a circulation pump, an auxiliary heater, a forcing/control function and an online plotter. The annual simulation output shows periodic and stable thermal behavior. Over the final part of the simulated year, the ambient temperature oscillates within a moderate range, while the collector and control-related variables exhibit repeated peaks associated with active solar collection and demand-driven operation.



Figure V. 4: Overall TRNSYS response showing ambient temperature, control-related variable, collector behavior, and result/output over the simulated period.

The ambient-temperature curve remains relatively smooth and varies approximately between 16°C and 33°C, over the displayed interval. This confirms that the weather input changes gradually and acts as the external boundary condition for the thermal system. In contrast, the control-related variable labelled “appoint” exhibits narrow periodic peaks that may reach approximately 135–155 in the displayed scale. Regardless of the exact internal naming used in the model, this behavior indicates a scheduled or controlled thermal response rather than a random fluctuation.

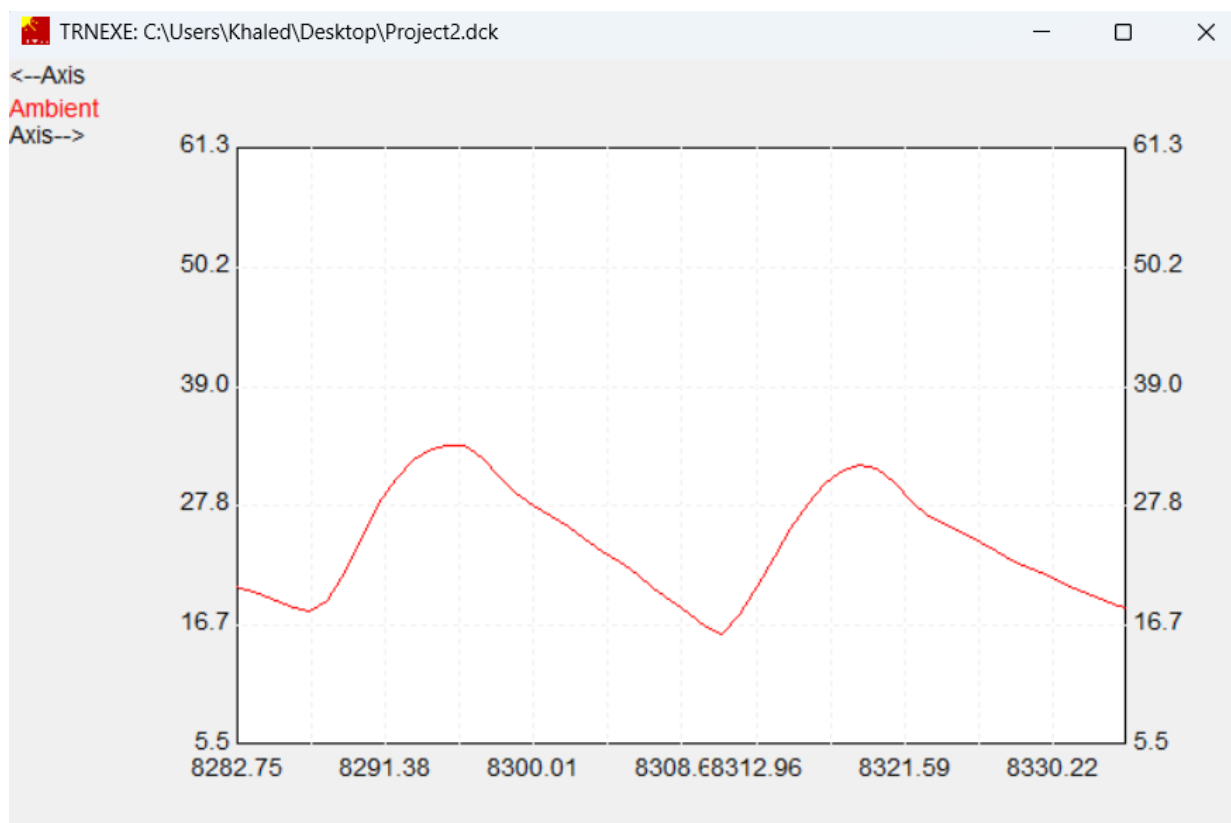


Figure V. 5: Ambient temperature evolution over a selected simulation interval.

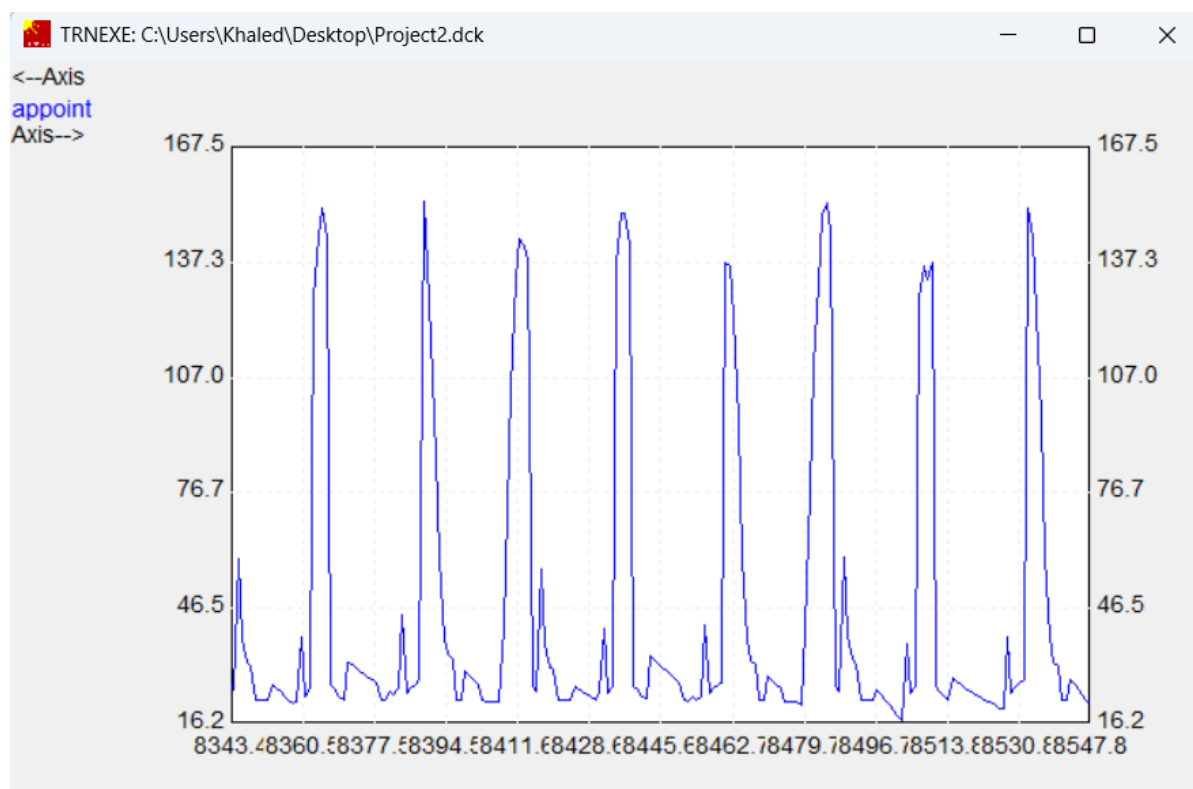


Figure V. 6: Periodic evolution of the control-related variable labelled “appoint.”

The collector variable displays the clearest evidence of solar thermal activation. The recorded peaks rise repeatedly to about 140–155, while the lower levels remain close to 10–30 between active periods. This strongly cyclical behavior is characteristic of a collector that charges thermally during solar availability and drops back when solar gain decreases or circulation conditions change. The fact that collector peaks are much higher than ambient temperature demonstrates a strong thermal lift and confirms that the solar field is effectively converting incident radiation into usable thermal energy.

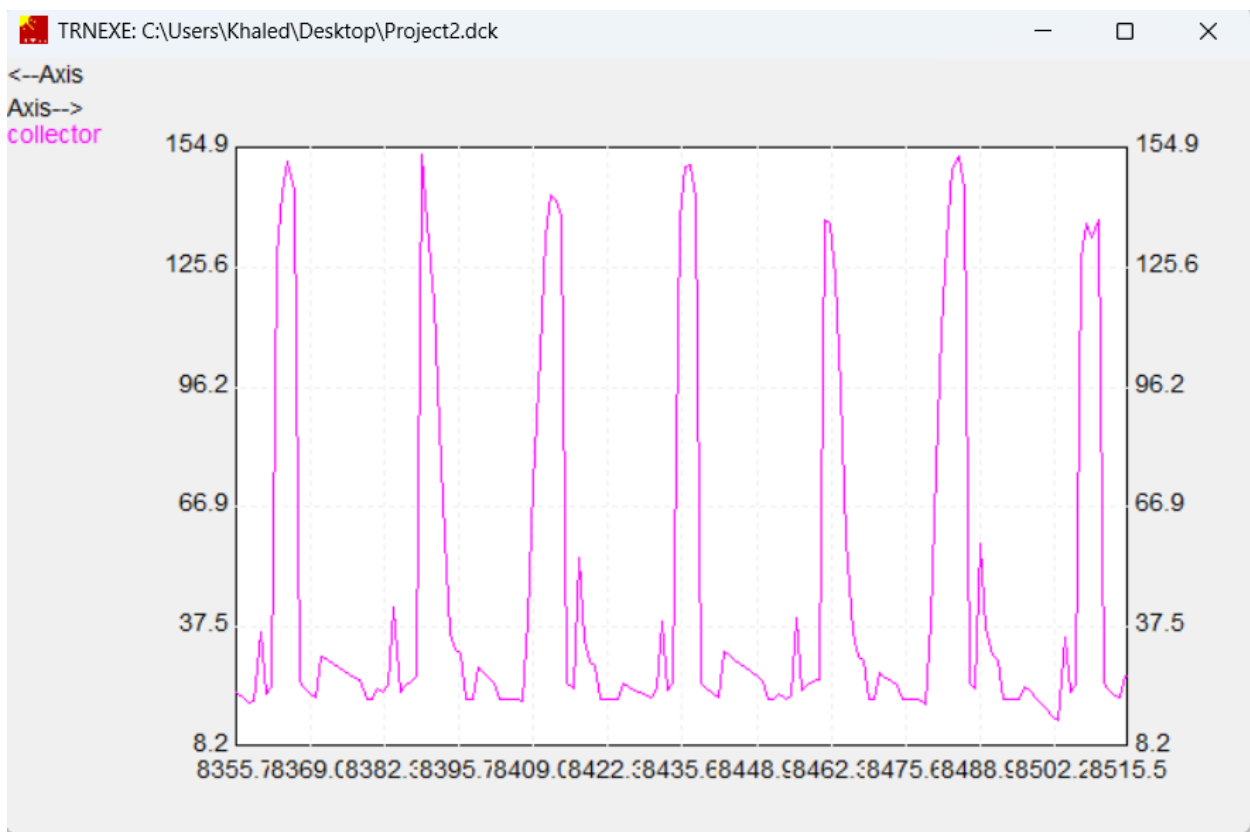


Figure V. 8: Collector thermal behavior showing repeated operating peaks during active solar periods.

The variable labelled “Result” follows a rectangular or step-like profile, alternating between a low level close to zero and a high plateau around 28–29. This profile is typical of an on/off output, a control command, or a delivered-heat indicator associated with demand satisfaction. Its regular repetition, synchronized with the collector and control peaks, shows that the system operates in a controlled sequence: solar energy is collected, thermal output is activated, and the system returns to a low state when the thermal condition or demand threshold is no longer satisfied.

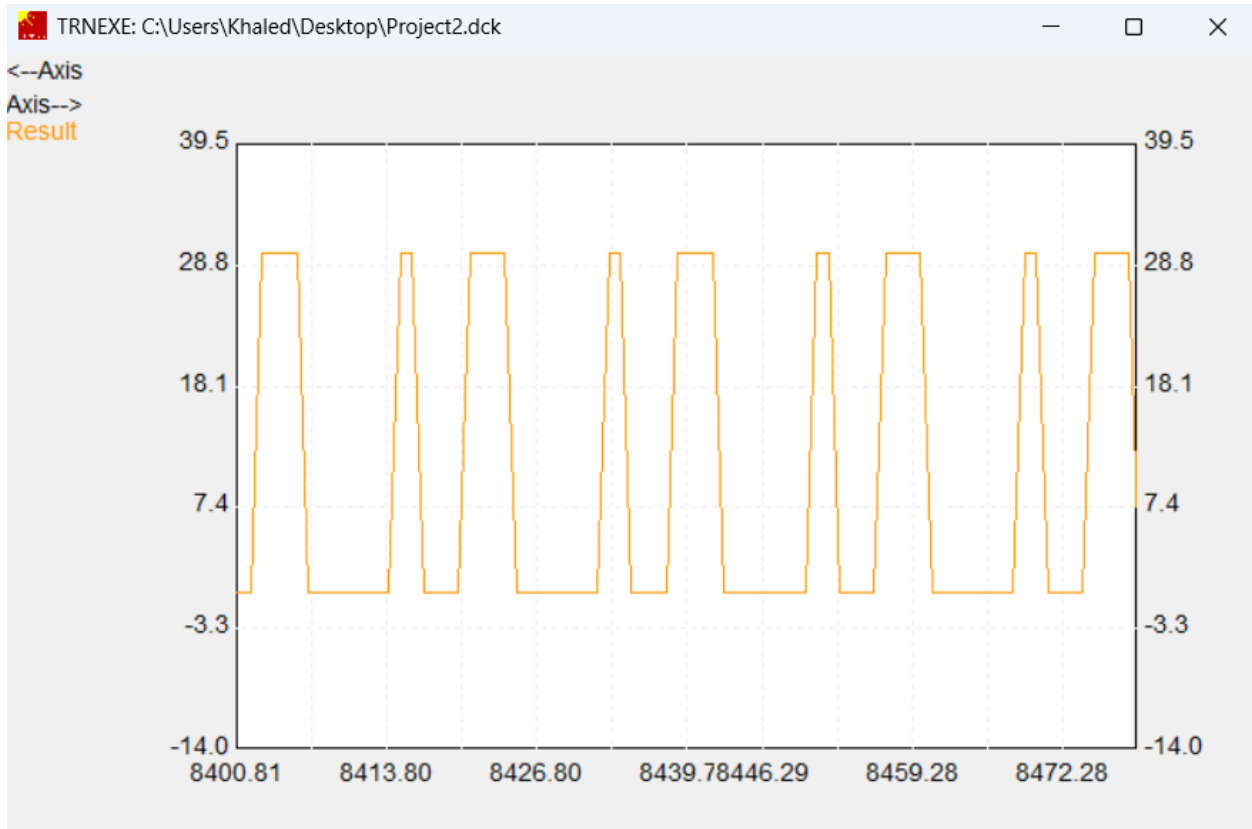


Figure V. 9: Step-like output/result signal associated with controlled system operation.

Taken together, these curves indicate coherent system operation. The collector responds strongly whenever solar conditions are favorable, the control variable organizes periodic activation, and the output variable reflects a stable thermal-delivery sequence. The simulated behavior therefore supports the technical feasibility of using a solar-assisted system for this application in Laghouat. The hottest months provide the most favorable solar operating conditions, while winter operation remains possible thanks to the combination of moderate winter irradiation and auxiliary backup.

V.5 Estimation of the Building Energy Needs

The estimation of the energy requirements of the studied building was carried out based on the thermal characteristics of the building envelope and the climatic conditions of the city of Laghouat. The assessment of the space-heating demand was performed in accordance with the Algerian Thermal Regulation (DTR C3.2), which provides a standardized methodology for evaluating heat losses through the various components of the building envelope, including external walls, roof, floor, doors, windows, and air infiltration. The overall heat loss coefficient was determined by summing transmission losses and ventilation losses.

The case study concerns a typical F3 residential apartment located in Laghouat, Algeria. The dwelling has a total floor area of approximately 100.1 m², an internal height of 2.80 m, and a conditioned volume of 254.8 m³. These geometric and architectural characteristics were used as the basis for evaluating the thermal performance of the building and determining its heating requirements.

To ensure a reliable assessment of thermal losses, the thermal resistances of the exterior walls, roof, and floor were calculated from the physical and thermophysical properties of the construction materials composing each building element. The resulting thermal transmittance values were subsequently employed to estimate heat transfer through the building envelope under winter operating conditions.

Furthermore, the domestic hot water (DHW) demand was estimated using an analytical approach based on the number of occupants and their average daily hot water consumption. The calculated heating and DHW energy demands constituted the fundamental design parameters for sizing the solar thermal system and evaluating its energetic performance under the climatic conditions of Laghouat.

The obtained results provide a comprehensive understanding of the building's thermal behavior and establish the basis for the design and optimization of the proposed solar heating system, ensuring adequate thermal comfort while reducing conventional energy consumption.

V.6 Conclusion

The results confirm that Laghouat offers a highly favorable environment for solar thermal applications. Meteorological data show strong solar irradiation throughout the year, with especially high values from April to September, while the temperature regime indicates that heating demand is mainly concentrated in winter and during nighttime conditions. For the studied F3 dwelling, the reference transmission heat loss reaches approximately 13.45 kW, with the roof and floor representing the largest shares of the losses.

The TRNSYS outputs demonstrate a repetitive and physically consistent operating pattern: ambient conditions evolve smoothly, the collector reaches high thermal peaks under solar input, and the system output follows a controlled intermittent sequence. This confirms that the proposed system can supply an important portion of the useful thermal demand through solar energy, while the auxiliary heater ensures continuity when solar production becomes insufficient. Overall, the study shows that the proposed solar-assisted configuration is technically well adapted to the climatic conditions of Laghouat and constitutes a relevant solution for reducing conventional energy consumption in the residential sector.

The assessment of energy consumption indicates that domestic hot water requirements and envelope heat losses are the primary drivers of the thermal demand of the examined house. A logical foundation for assessing system sizing and operation is provided by the updated calculations, which show a space-heating requirement of around 6.12 kW and a household hot water demand of roughly 361.67 kWh/month. His demand may be mostly met by the solar thermal system in Laghouat climate, which is marked by strong solar availability; the auxiliary heater only serves as a supplemental source when there is inadequate solar gain. According to the simulation results, the suggested method improves energy efficiency and lessens reliance on traditional energy sources by achieving a balanced interplay between predicted building demand, available solar energy, and backup heating.

General Conclusion

This study examined the potential contribution of solar thermal energy systems for space heating and domestic hot water generation, as well as the energy requirements of a model residential structure in Laghouat, Algeria. Using the TRNSYS software framework, the project included dynamic modeling, thermal calculations, and climatic analysis. Laghouat benefits from remarkable solar potential, which is characterized by high solar irradiation and lengthy sunlight duration throughout the year, according to an examination of the region's climate. Solar energy is one of the best renewable energy sources for sustainable energy applications in Algeria because of the country's ideal climate.

The thermal study of the prototype F3 building allowed the determination of the heat losses through the building envelope according to the Algerian thermal regulation DTR C3.2. The calculations showed that the roof represents the largest source of thermal losses, followed by the floor and exterior walls. The total transmission heat losses were estimated at approximately 13.45 kW, highlighting the importance of improving thermal insulation in residential buildings to reduce energy consumption and enhance thermal comfort.

The functioning of solar water heating systems, comprising solar collectors, storage tanks, hydraulic circuits, control systems, and auxiliary heating devices, were also investigated in parallel. According to the research, solar thermal systems are an effective and sustainable way to lessen reliance on traditional energy sources while maintaining continuous home hot water supply.

The evaluation of the system behavior under actual operating circumstances was made possible by the dynamic simulation carried out utilizing TRNSYS and Meteonorm meteorological data. The simulation's findings showed how well the solar heating system worked to meet a sizable portion of the building's thermal energy requirements, especially during times of strong solar radiation. The outcomes further validated TRNSYS dependability as an effective modeling, sizing, and optimization tool for solar thermal facilities.

All things considered, this study shows how promising it is to incorporate solar thermal technology into Algerian residential structures. Adoption of such systems promotes sustainable development and energy independence in addition to reducing greenhouse gas emissions and conserving energy. In order to maximize system performance and minimize heat losses, it is still crucial to optimize solar system size and improve building insulation.

The assessment of energy consumption indicates that domestic hot water requirements and envelope heat losses are the primary drivers of the thermal demand of the examined house. A logical foundation for assessing

system sizing and operation is provided by the updated calculations, which show a space-heating requirement of around 6.12 kW and a household hot water demand of roughly 361.67 kWh/month. His demand may be mostly met by the solar thermal system in Laghouat climate, which is marked by strong solar availability; the auxiliary heater only serves as a supplemental source when there is inadequate solar gain. According to the simulation results, the suggested method improves energy efficiency and lessens reliance on traditional energy sources by achieving a balanced interplay between predicted building demand, available solar energy, and backup heating

Finally, future research on the integration of renewable energy in buildings, particularly in semi-arid and Saharan locations, may find this work to be a helpful resource. Economic analysis, hybrid renewable system optimization, photovoltaic technology integration, and experimental validation of the predicted findings under actual operational circumstances are possible future projects.

References and Bibliographies

- [1] NASA Science — Solar System. <https://science.nasa.gov/solar-system/>
- [2] Global Solar Atlas — Algeria. <https://globalsolaratlas.info/download/algeria>
- [3] Chellali et al., A Review on solar radiation assessment and forecasting in Algeria.
<https://www.ajss.dz/index.php/ajss/article/view/133>
- [4] Pacific Northwest National Laboratory (PNNL) — Solar Water Heating Systems.
<https://www.pnnl.gov/projects/om-best-practices/solar-water-heating-systems>
- [5] International Code Council — Code Notes: Solar Water Heating Systems.
<https://www.iccsafe.org/building-safety-journal/bsj-technical/codenotes-solar-waterheating-systems-2/>
- [6] U.S. Department of Energy — Solar Water Heaters.
<https://www.energy.gov/energysaver/solar-water-heaters>
- [7] IPCC AR6 WGIII Chapter 6 — Energy Systems.
<https://www.ipcc.ch/report/ar6/wg3/chapter/chapter-6/>
- [8] UNECE — Life Cycle Assessment of Electricity Generation Options.
https://unece.org/sites/default/files/2021-11/LCA_final.pdf
- [9] Harvard University — Solar Altitude and Azimuth Angle Calculation.
<https://courses.seas.harvard.edu/climate/eli/Courses/EPS231/Sources/06-Glacial/2Milankovitch/more/zenith-angle-calculation-Guoyuan-Li.pdf>
- [10] PVsyst Basic Documentation — Irradiance and Solar Geometry.
<https://www.pvsyst.com/help-basic/en/technical-tools/photovoltaic-generation/sunenergy-source/irradiance-solar-geometry.html>
- [11] NASA/GSFC — Radiation Laws and Blackbody Radiation.

https://asd.gsfc.nasa.gov/archive/mwmw/mmw_bbody.html

[12] Meteonorm — Climate Data for PV Planning & Building Simulation.

<https://meteonorm.com/climate/>

[13] TRNSYS 18 — Volume 3 Standard Component Library Overview.

<https://www.trnsys.com/assets/docs/03-ComponentLibraryOverview.pdf>

[14] U.S. Department of Energy — Insulation and R-Value Basics.

<https://www.energy.gov/energysaver/insulation>

[15] About the regulatory framework for improving the energy efficiency of

buildings: Algerian Context (DTR C3.2/4 overview).

<https://journal.iccaua.com/jiccaua/article/download/101/98/275>

[16] Energy Plus Engineering Reference — Solar Collectors.

<https://bigladdersoftware.com/epx/docs/8-5/engineering-reference/solar-collectors.html>

[17] Weather Spark — Average Weather in Laghouat, Algeria.

<https://weatherspark.com/y/47078/Average-Weather-in-Laghouat-Algeria>

[18] Review of Solar Thermal Water Heater Simulations Using TRNSYS.

<https://ieeexplore.ieee.org/abstract/document/7312251/>

[19] Solar gis — Free Solar Maps & GIS Data for Algeria.

<https://solargis.com/resources/free-maps-and-gis-data?locality=algeria>

[20] IEA — World Energy Mix / Total Energy Supply.

<https://www.iea.org/world/energy-mix>

[21] Grand View Research — Solar Water Heaters Market Size and Share

Report. <https://www.grandviewresearch.com/industry-analysis/solar-water-heatersmarket>

Abstract

Improving energy efficiency in buildings is one of the most important solutions adopted to reduce energy consumption and greenhouse gas emissions, especially given the global trend towards using renewable energy and achieving sustainable development. An integrated solar heating system is defined as a system that uses solar energy to provide both potable hot water and domestic heating.

This study aims to assess the energy needs of a typical F3 residential building located in Laghouat, by estimating the heating and potable hot water requirements. The regulatory technical document *DTR C3.2* was used to determine the heating energy demand and verify the building's compliance with the thermal regulations in force in Algeria, while the potable hot water requirements were assessed using an analytical methodology.

A thermal simulation of the potable hot water production system was also conducted using TRNSYS software.

Keywords: Energy Needs Assessment, Model Building, Solar Heating System, Domestic Hot Water, Thermal Losses, Energy Efficiency, TRNSYS, System Sizing

ملخص

يُعدّ تحسين كفاءة الطاقة في المباني من أهم الحلول المعتمدة للحد من استهلاك الطاقة وتقليل انبعاثات غازات الاحتباس الحراري، خاصة في ظل التوجه العالمي نحو استخدام الطاقات المتجددة وتحقيق التنمية المستدامة. ويُعرّف نظام التدفئة الشمسية المتكامل بأنه نظام يعتمد على الطاقة الشمسية لتوفير كلّ من الماء الساخن الصحي والتدفئة المنزلية.

تهدف هذه الدراسة إلى تقييم احتياجات الطاقة لمبنى سكني نموذجي من نوع F3 يقع بمدينة الاغواط، وذلك من خلال تقدير متطلبات التدفئة والمياه الساخنة الصحية. وقد تم الاعتماد على الوثيقة التقنية التنظيمية *DTR C3.2* لتحديد الطلب على طاقة التدفئة والتحقق من مدى مطابقة المبنى للوائح الحرارية المعمول بها في الجزائر، بينما تم تقييم احتياجات الماء الساخن الصحي باستخدام المنهجية التحليلية.

TRNSYS. كما أُجريت محاكاة حرارية لنظام إنتاج الماء الساخن الصحي باستعمال برنامج

الكلمات المفتاحية:

تقييم احتياجات الطاقة، المبنى النموذجي، نظام التسخين الشمسي، المياه الساخنة الصحية، الفواقد الحرارية، كفاءة الطاقة، تحديد أبعاد النظام، TRNSYS