

Powering The Past For a Sustainable Future: Solar energy integrating in the Archaeological Ksar of Sfisifa

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Abstract

The historic, compact urban fabrics of Algeria, known as Ksour (plural of Ksar), are fundamental pillars in shaping the collective memory and cultural identity of its communities. These are not merely architectural structures but living records of a society's culture, intellectual unity, and historical methodologies, reflecting a deep interaction with the environment and fulfilling social necessities. In the context of the global shift towards sustainability and the exploration of clean energy solutions, solar power emerges as a strategic and ideal option, particularly for desert regions blessed with abundant solar irradiation year-round. The integration of solar panels into the rehabilitation of desert Ksour, specifically Ksar Sfisifa, presents a promising opportunity to achieve multiple objectives. These include providing a clean and sustainable energy source, reducing operational costs, and enhancing the heritage and functional value of these historic buildings. This research aims to explore and develop an effective strategy for the rehabilitation of Ksar Sfisifa through the integration of solar panels in a manner that is harmonious with its historical character and addresses future preservation challenges.

Keywords : Ksar Sfisifa ; Photovoltaics (PV) ; Architectural Integration ; Sustainable Rehabilitation; Feasibility Study.

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I- Introduction :

Solar energy is one of the most significant renewable and inexhaustible natural resources. It has been harnessed by humanity since antiquity for various applications, such as crop drying, pottery making, and home heating.

This energy, manifested as light and heat radiation from the sun, reaches Earth after a journey of approximately eight minutes. It can be utilized directly or converted into other forms, such as electricity through the photovoltaic effect or thermal energy. The photovoltaic conversion relies on solar cells, typically made of semiconductor materials like silicon, to directly transform solar radiation into electricity. This phenomenon was discovered in the late 19th century, and Albert Einstein was awarded the Nobel Prize in 1921 for his explanation of it. From another perspective, the adaptive reuse of desert Ksour is a sustainable and economically viable choice. It avoids the high costs of new construction and ensures the continuity of historic buildings by assigning them new functions. This approach is considered one of the best methods for heritage preservation, as the income generated from the new use can fund the necessary maintenance and protection. Given Algeria's vast solar resources, with an average annual sunshine duration exceeding 2,100 hours and reaching up to 3,500 hours in the Sahara, modern scientific research is increasingly focused on leveraging this potential.

This includes applications in the rehabilitation of archaeological sites like the Ksour. Many of these historic settlements face the risk of deterioration due to environmental factors, inappropriate interventions, or neglect. This context raises critical questions about the rationale and methods for using solar energy in their preservation and whether this integration should be part of the initial rehabilitation planning.

Research Problem: What are the most effective architectural and operational methods for integrating solar panels into Ksar Sfisifa to ensure its heritage and architectural values are preserved while enhancing its sustainability?

This study aims to provide practical solutions for the preservation of Ksar Sfisifa by integrating solar energy systems according to specific standards. This approach is designed to ensure the Ksar's sustainability without compromising its historical value, while also mitigating visual distortion and improving the urban landscape.

I.1. Ksar Sfisifa: Characteristics, Importance, and Current Challenges

The architectural heritage of the Algerian Sahara reflects a profound understanding of the local environment.

The Ksour were designed as a direct response to the prevailing climatic, geographical, social, and economic conditions, embodying a unique integration of architectural design with the needs of the community, while adhering to Islamic principles and traditional customs. (حملاوي، 2008، ص 57).

1.1. A Historical Overview of Ksar Sfisifa Ksar Sfisifa is part of a chain of Ksour and Kasbahs that stretches along the western part of the Saharan Atlas in Algeria, (ميخوت، 2018، ص 105-107). in a region known as the "Mountains of the Ksour" (Jibal al-Ksour). The Ksar derives its name from the willow trees (safsaf) that were once abundant in the area. Historical sources indicate that the Ksar's foundation dates back more than a thousand years to the second half of the 4th century AH (10th century AD). It was established by the descendants of Sharif Moulay Ahmed ben Ziane al-Wadghiri al-Idrissi and attracted tribes from various regions, including Tlemcen, Seb Dou, the Sahara, and the mountains of Amour. This settlement occurred after the departure of the Zenata tribe from the nearby Ksar of Taghilout. Notably, the tombs of the ancestors of the Beni Amer tribe still exist on the edge of the great valley, attesting to the region's deep historical roots.

The Ksar was built in successive historical phases, reflecting the continuous social and urban evolution of the area. (بن عمارة، 2014، ص 119).

It served as a vital center for its inhabitants, providing shelter and protection in a harsh desert environment. It also played a pivotal role in religious life, housing an ancient mosque that dates back to the Ksar's founding period.

Geographical Location:

The Ksar is located approximately 30 kilometers west of the city of Ain Sefra, on the right bank of the Sfisifa valley. It was officially classified on the supplementary inventory list of cultural heritage by Decree No. 541 on September 23, 2010. The Ksar covers an area of approximately 4.2 hectares. It is bordered to the north by the departmental road RW-05 and buildings from the French colonial era, and to the south by the Sfisifa cemetery. To the west and southwest, a path runs alongside the Ksar, followed by a historic wall made of mud and stone, punctuated by openings leading to palm groves owned by the region's historic families.

1.2. Architectural and Design Characteristics of the Ksar

Ksar Sfisifa possesses unique architectural features that demonstrate a sophisticated understanding of sustainable design and adaptation to the desert climate. These characteristics are evident in the following aspects:

Building Materials: The construction of the Ksar primarily relied on locally sourced materials from the desert environment, such as stone and mud brick.

This choice provided excellent natural thermal insulation, helping to maintain cool indoor temperatures during the hot summer and warmth during the cold winter. The reddish-brown color of the soil also gave the Ksar's walls an aesthetic quality that blends harmoniously with the surrounding mountainous landscape.

Urban Layout: The Ksar features an organic layout that conforms to the site's topography, (عبد الله، 2013، ص107). It consists of a compact fabric of contiguous dwellings and narrow alleyways that provide shade and reduce the impact of hot winds, creating a more temperate and comfortable internal microclimate.

Defensive Towers: The Ksar was fortified with helical-shaped towers at its main entrances, which served defensive (عاصم، 2000، ص153) purposes and provided strategic observation points. These towers were not only functional but also added a distinctive aesthetic element to the Ksar's character.

Narrow Alleyways: The alleys within the Ksar were designed to be narrow, and some are covered, providing protection for pedestrians from direct sunlight and summer heat while minimizing heat loss in winter. Their winding design also helps to break the force of desert winds.

Rooftops: The roofs of the desert Ksour are typically flat, providing additional space for various activities, (بن يوسف، 1992، ص85) such as drying crops or sleeping outdoors on mild summer nights. These flat roofs also contribute to the thermal insulation of the building.

Fig.1. The partitioning of the Ksar Into residential complexes

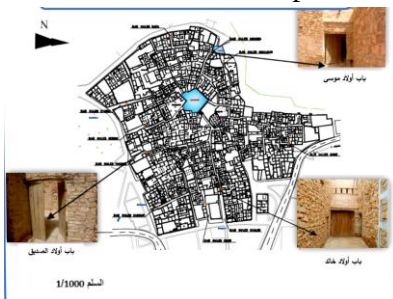
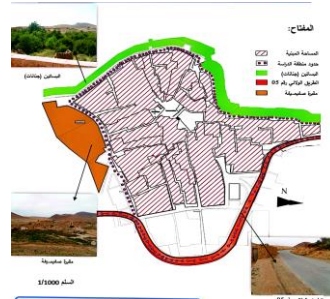


Fig.2. The limits of the Ksar



1.3 The Current Condition and Challenges Facing Ksar Sfisifa

Despite its significant historical and architectural value, Ksar Sfisifa currently faces a range of serious challenges that threaten its survival and necessitate urgent intervention for its rehabilitation. These challenges can be summarized as follows:

Urban Deterioration: The Ksar suffers from accelerated natural decay due to harsh environmental factors. The Saharan climate, characterized by strong winds, rare but intense rainfall, and significant temperature fluctuations between day and night, negatively impacts the traditional building materials and leads to the erosion of its architectural structures over time.

Human Neglect: The lack of periodic maintenance and general neglect contribute to speeding up the deterioration process. Furthermore, unplanned urban expansion in the surrounding areas can adversely affect the unique historical character of the Ksar and its environment.

The Need for Energy: Should the Ksar be rehabilitated for modern uses (residential, touristic, or cultural), a pressing need will arise for sustainable energy sources and modern water and sanitation systems. This need, while a challenge, also presents an ideal opportunity to integrate renewable energy solutions.

Lack of Comprehensive Documentation: There may be a shortage of detailed studies and documentation regarding the Ksar's structural and architectural condition. This deficiency makes the planning process for rehabilitation projects more complex and challenging.

I. 2. Solar Energy A Strategic Resource for Sustainable Development:

Generation has become widespread. These panels are composed of silicon, which interacts with sunlight to generate a direct electric current (DC). This current is then converted into an alternating current (AC) by an inverter to power various electrical appliances within buildings. (Boudjerir, 2010, p 33-35.)

Water Heating: Solar water heaters are one of the oldest and most important applications of solar thermal energy. These heaters are available in various types and forms and are used to provide hot water for domestic and industrial applications. (Ben arima, 2012, p 7-12.)

Cooking (Solar Ovens): These ovens were designed as an eco-friendly and economical alternative for cooking, especially on camping trips and in remote areas. A solar oven consists of an insulated box with a glass lid that allows sunlight to enter and traps heat inside. Temperatures can reach approximately 181°C (358°F), sufficient for slow-cooking food. (Selami, 2000, p 9-13.)

Heating and Cooling: Both passive and active solar energy systems are used to heat homes in cold regions. Conversely, innovative solar cooling technologies can be employed in hot areas, providing integrated solutions for indoor climate control in buildings. (**Alternative Energy Sourcebook**, p 365.)

Lighting: Solar lighting systems are a rapidly expanding application, suitable for both indoor and outdoor use. These systems are available in various sizes and shapes, making them an ideal choice for residential and commercial use, and they play a crucial role in providing light to areas not connected to the electrical grid. (.ص52، 2006، ميهوب)

Charging: Various electronic devices, such as phones and laptops, can be charged using solar-powered chargers. These chargers work by storing energy in internal batteries, allowing them to be used to charge devices at any time and in any place.

2.2. Solar Radiation: Concept and Types

Solar radiation is defined as the amount of solar energy that falls on a specific area and is the primary source for photovoltaic power generation. Only a tiny fraction of the sun's total energy (estimated at one part in two billion) reaches the Earth's surface, but this amount is responsible for all forms of energy on our planet. (**Ababsa**, 2009, p25- 30.)

Solar radiation is characterized by its variable intensity throughout the day, reaching its peak at noon when the sun's rays are perpendicular to the Earth's surface. (**Ababsa**, ibid. p25- 30.) The intensity of solar radiation can be measured practically using a device called a pyrometer. (**Boutebila**, 2012, p19-27.)

The solar radiation that reaches us consists of three main types:

Direct Normal Irradiance (DNI): This is the radiation that travels directly from the sun to the Earth's surface without being scattered. This type of radiation is the most intense and is directly affected by any obstacle (such as clouds or buildings) located between the sun and the point of measurement. (**Tabet**, 2010, p17.)

Diffuse Horizontal Irradiance (DHI): This is the radiation that reaches the Earth's surface after being reflected or scattered by components of the atmosphere (such as clouds and dust particles) or other surfaces (like adjacent buildings). Although its source is also the sun, it reaches the location from multiple directions, (.ص73، 2002، مندور) not directly from the solar disk.

Global Horizontal Irradiance (GHI): This is the total sum of Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI) that strikes a specific horizontal surface.

This measurement is the most important (مندور، المرجع السابق، ص73) when assessing the potential for solar energy generation at a given location.

2.3. Types of Solar Energy Systems

Photovoltaic (PV) System:

This is the most common system for generating electricity from solar energy. It consists of several key components.

Solar Panels: Receive sunlight and convert it directly into direct current (DC) electricity.

Inverter: Converts the direct current (DC) into alternating current (AC) that can be used in buildings.

Other Components: Include mounting structures, cables, and electrical accessories necessary for the system to operate efficiently and safely.

When designing a PV system, (عبد الله قاسم، 2023، ص4)، it is essential to select panels with high efficiency and resistance to heat and dust to ensure stable performance.

Solar Thermal Systems: These systems are used to heat water or air. They can be an ideal solution for providing hot water for various uses within the Ksar after its rehabilitation or for implementing passive heating systems during the winter.

Solar Glass: This is an innovative technology that integrates photovoltaic cells into glass. Transparent or semi-transparent solar glass can be used as a substitute for traditional windows or in building facades. This technology allows natural light to pass through while simultaneously generating electricity, offering a solution that combines aesthetics and functionality, making it ideal for heritage buildings.

Solar Tracking Systems: These are mechanical systems that orient solar panels to follow the sun's movement throughout the day. Although they are more complex and costly than fixed systems, they can significantly increase energy generation efficiency (by up to 25-40%), especially in regions with high solar radiation like the Sahara.

2.4 Types of Photovoltaic Cells

Photovoltaic cells are made from semiconductor materials, with silicon being the most commonly used. A cell consists of two layers of silicon: one treated to create a surplus of electrons (n-type layer) and the other treated to create a deficit (p-type layer). When sunlight strikes the cell, it liberates electrons, which flow from the n-type to the p-type layer through an external electrical circuit, generating an electric current. PV cells vary based on their silicon manufacturing method, with the most prominent types being:

Monocrystalline Cells: Made from high-purity silicon ingots, giving them a uniform crystal structure. They boast the highest energy conversion

efficiency among commercial types (up to 22% or more) and have a long lifespan. However, their complex manufacturing process makes them the most expensive. (عبد الله قاسم، المرجع السابق، ص5). They are recognizable by their uniform black appearance and rounded edges.

Polycrystalline Cells: Made by melting raw silicon fragments and pouring them into square molds, resulting in a non-uniform crystal structure. They are slightly less efficient than monocrystalline cells (with efficiency ranging from 15% to 20%), but their cost is lower, and their manufacturing process is simpler. They can be identified by their non-uniform blue appearance, (عبد الله قاسم، المرجع السابق، ص6), which reflects the boundaries of the different crystals.

Thin-Film Cells: Manufactured by depositing a very thin layer of photovoltaic material (such as amorphous silicon, a-Si, or other materials) onto a flexible or rigid substrate. These cells are characterized by their flexibility and light weight, allowing for easy integration into various surfaces. Their efficiency is lower than that of crystalline cells, but their cost is also lower, and they are relatively less affected by high temperatures.

Ribbon Silicon Cells: A technology that aims to combine some of the advantages of monocrystalline cells with lower production costs by pulling thin ribbons directly from molten silicon, which reduces material waste.

Fig.3. Monocrystalline Cells

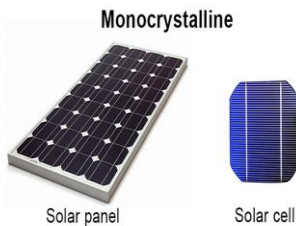


Fig.4. Polycrystalline Cells



I. 3. Potential and Challenges of Integrating Solar Energy in Ksar Sfisifa

Integrating solar energy systems into heritage buildings and desert Ksour presents a delicate architectural and technical challenge, requiring a difficult balance between sustainability requirements and the preservation of the building's historical identity. This integration can be achieved by installing panels on the ground (sometimes with dual uses for grazing or agriculture)

or by incorporating them directly into the building's structure (roofs and walls), a practice known as Building-Integrated Photovoltaics (BIPV). (ستيفان، كراوتر، 2011)

3.1. Climatic Conditions and Solar Radiation at the Ksar Site

The Ksar Sfisifa region is characterized by climatic conditions that make it ideal for harnessing solar energy:

Abundant Solar Radiation: The area receives very high levels of solar radiation (أرشيف محطة الأرصاد الجوية لولاية النعامة لسنوات 2008-2011) throughout the year, with an average of over 3,000 hours of sunshine annually. This means that solar panels can operate at high efficiency for most of the year.

High Temperatures: Although high summer temperatures (Armieux, p79) can reduce the efficiency of some types of solar panels, modern manufacturing technologies have made panels more heat-resistant. Furthermore, good installation designs that allow for ventilation behind the panels can mitigate this effect.

Low Humidity: Low humidity helps maintain the clarity of the atmosphere, allowing a greater amount of solar radiation to reach the Earth's surface.

3.2. Key Challenges for Integrating Solar Panels in the Ksar:

Despite the promising opportunities, the project of integrating solar energy into Ksar Sfisifa involves unique challenges that require innovative solutions and careful study. These can be categorized as:

3.2.1. Aesthetic and Architectural Challenges:

Preserving the Authentic Appearance: The Ksar is distinguished by its traditional architectural character and natural materials (stone and mud brick). The thoughtless addition of modern solar panels could disfigure this authentic appearance (النمرة، 2014، المجلد 7) and conflict with its historical aesthetic.

Compatibility with Original Materials: The installation techniques for solar panels must be compatible with the Ksar's traditional building materials, without causing damage or affecting their physical properties, such as natural ventilation and thermal insulation.

Visual Impact from the Outside: The appearance of the panels from various surrounding viewpoints must be carefully considered, especially since the Ksar is a historical landmark with high visual value.

3.2.2. Structural and Engineering Challenges:

Load-Bearing Capacity of Structures: The old structures of the Ksar, especially the roofs, may not have been designed to bear the additional weight of solar panels and their mounting systems. This requires a thorough structural assessment to ensure the building's safety and determine if reinforcement is needed.

Modifications to the Building: The installation process may require modifications to the building, such as drilling holes in walls or roofs to run cables or fix structures. These modifications must be minimal and, where possible, reversible to preserve the historical fabric of the building.

3.2.3 Regulatory and Legal Challenges:

Heritage Preservation Laws: As a classified historical monument, Ksar Sfisifa is subject to strict laws and regulations aimed at preserving heritage.

(دحدوح، 2007-2008، ص130). These laws may impose restrictions on the types of modifications allowed and require special approvals from the relevant heritage authorities.

3.2.4 Economic and Operational Challenges:

Initial Cost: The cost of integrating solar panels into a historic building may be higher than in a modern building due to the need for custom design and installation solutions, special materials, and specialized labor experienced in dealing with heritage buildings.

Maintenance: Solar panels require periodic maintenance, especially in a dusty desert environment. The installation solutions must be designed to allow easy access for cleaning and maintenance without damaging the building.

3.3 Proposed Technical Solutions for Integrating Solar Panels in Ksar Sfisifa

To overcome the aforementioned challenges, a set of innovative technical solutions can be adopted to balance modernity with authenticity.

Licensing Procedures:

1. Initial Consultation: The project must begin with early communication with the relevant authorities, such as the Directorate of Culture and Arts and certified architectural firms, to request clear guidance on the necessary requirements and procedures.

2. Comprehensive File Preparation: A complete license application file must be prepared, including architectural plans, a visual impact study, and a structural assessment.

3. Obtaining Approvals: The project requires approvals from several entities, including the electricity service provider (if the system is to be grid-connected) and the Directorate of Culture and Arts, to ensure compliance with heritage protection laws.

Licensing Requirements:

If the electrical capacity of the solar panel system to be installed on the building exceeds 50 kW, the following must be achieved: - Obtain approval from the electricity service provider.

-Secure approval from the provincial Directorate of Culture and Arts.

- Contract with an architectural engineering firm qualified by the Directorate of Culture and Arts.

3.4. Structural and Architectural Requirements for the Solar Energy System

Before commencing any work, the project consultant must conduct a thorough and comprehensive inspection of the Ksar to assess its structural condition and its ability to bear additional loads, (**Parameshwaran, Kalaiselvam, 2012, p 2433 -2394**)

(in accordance with approved technical standards (such as the Saudi Building Code, SBC 301, for loads and forces).

The technical report must include:

3.4.1 Substructure Installation (Foundations, Columns, Roofs):

Foundations:

- Assess the impact of environmental factors on the structure, such as humidity, salt-laden air, acids, or chemical vapors.
- Ensure there is no subsidence in the foundations due to cracks, the presence of termites, or damage and erosion from groundwater.

Columns:

- If the loads exceed the design capacity of the building, the structure must be reinforced according to architectural conservation standards and structural analysis, following the guidance of the architectural firm and the Directorate of Culture and Arts.
- Check for the absence of longitudinal cracks, corrosion of the column's covering, (**Eames, Norton, N47, p 2733 - 2715**) or any tilting or deviation.

Roofs:

- Verify the integrity of the roof, ensuring there is no sagging, concrete damage, or corrosion of reinforcing steel.
- Confirm the roof's structural capacity and that it does not require additional support.
- Ensure a fully functional water drainage system is in place to prevent water stagnation.
- For sloped roofs, the building structure must be reinforced to handle additional wind loads, (**Eames, Norton, ibid, p2733 – 2715**) adhering to building codes and heritage preservation laws.

3.4.2. Determining Optimal Installation Locations:

The project's success heavily depends on selecting appropriate locations for panel installation to maximize energy generation with minimal visual impact.

The available options include:

Flat Roofs: A characteristic feature of Saharan architecture, flat roofs are among the best locations for solar panel installation.

Low-profile, non-visible support structures can be designed, or panels can be integrated directly into the roof design.

Internal Courtyards: If the courtyards are sufficiently large and receive adequate solar radiation, transparent or semi-transparent solar panels can be installed as partial coverings (pergolas), providing shade and generating power simultaneously.

Non-Visible Adjoining Areas: If there are areas not directly visible from the main viewpoints (such as rear roofs or adjacent lands), they can be used to install larger, conventional solar systems, with the power being connected to the Ksar via underground cables.

Fig.4.The Ksar courtyard



Fig.5. The Ksar's rear facade



I. 4. Proposed Technical Solutions and Expected Benefits:

To overcome these challenges, a range of innovative technical solutions that balance modernity and authenticity can be adopted. These include using BIPV, thin-film cells, and colored or transparent panels that blend with the original architecture.

4.1. Installation Methods for Solar Panels in Ksar Sfisifa

The underlying roof structure must be inspected and any damage repaired before commencing installation work. (**Technology Roadmap**, [IEA2011], p 19-16.) All penetrations in the roofs and walls for cable mounts must be sealed and insulated to prevent water leakage and pest intrusion. The materials used must be fire-resistant. The highest point of the solar panels should not exceed the height of the roof's parapet to avoid exposure to wind uplift forces and to maintain the building's aesthetic profile. Cable pathways should be concealed, (**Solar heat worldwide**, [IEASHC2013], p 40-38.) using external conduits where necessary, especially in historic buildings.

Tab.1.Solar Panel Mounting Methods

Surface Type	Proposed Installation Method	Mounting System	Notes
Sloped Roof	Hook based mounting, Special tile mounts	Single or double-layer rails	Must ensure the integrity of the original waterproofing system
Flat Roof	Penetrative(bolted) or non-penetrative (ballasted)	Metal rails	Ballasted systems are preferred to avoid drilling into historic surfaces
Ground	Concrete foundation mounting	Ground screws or foundations	Used for adjacent, non-visible areas.

4.2. Proposed Suitable Solar Panel Types

1. Building-Integrated Photovoltaics (BIPV): (Kalogirou, 2009, p1-75)

These panels are the optimal solution for preserving the original appearance. They can be integrated as a replacement for traditional building materials on roofs or facades, making them an indistinguishable part of the architectural design.

2. Thin-Film Solar Panels: These panels are lightweight and flexible, allowing them to be installed on surfaces that may not support the weight of traditional panels. They can be adhered directly to surfaces without requiring bulky mounting structures.

3. Modern Technologies to Reduce Visual Impact:

Colored Solar Panels: Modern techniques allow for the manufacturing of solar panels in colors that match traditional building materials like stone or terracotta, helping them blend almost seamlessly with the original design.

Transparent Solar Panels: These can be used in windows or glass roofs (skylights) to preserve architectural aesthetics and allow natural light to pass through while generating electricity.

4.3. Performance and Feasibility Assessment

To ensure the success of the Ksar Sfisifa integration project, a thorough assessment of the expected performance and technical feasibility of the proposed systems is essential. This evaluation includes:

Energy Yield Estimation: Calculating the amount of energy the proposed system can generate based on local solar irradiance data (GHI, DNI), panel efficiency, orientation, and potential shading. This helps in sizing the system to meet the Ksar's energy needs.

Technical Feasibility Analysis: Evaluating the structural, architectural, and electrical compatibility of the proposed system with the historic building. This includes the load-bearing capacity analysis, the installation plan, and the grid-connection strategy.

Environmental Impact Analysis: (Duffie, Beckman, 1980, p 470 -1) Assessing the positive environmental impact of the project, such as the reduction in carbon emissions by replacing conventional energy sources.

4.3.1. Social and Cultural Benefits:

Heritage Preservation: Integrating solar energy ensures the continued use and functionality of the Ksar, directly contributing to the preservation of this historical monument for future generations and protecting it from decay and neglect.

Improving Quality of Life: Whether the Ksar is used for residential, touristic, or cultural purposes, providing sustainable energy will improve the quality of available services (such as lighting and cooling), enhancing the comfort of residents and visitors

Promoting Environmental and Heritage Awareness: The Ksar will become a living model of the successful integration of heritage and modern technology, (**Solar** heating and Cooling, [ESTTP 2008] p 15-14.) raising awareness of the importance of sustainability and heritage preservation among the local community and visitors.

4.3.2. Economic Benefits:

Reducing Operating Costs: In the long term, generating electricity from solar energy will lead to a significant reduction in electricity bills or fuel costs, freeing up financial resources that can be reinvested in the maintenance and development of the Ksar.

Creating Job Opportunities: The project can create local jobs in the fields of installation, maintenance, and cleaning of solar energy systems, in addition to enhancing local technical expertise in this field.

Promoting Sustainable Tourism: After its rehabilitation, the Ksar can become a model destination for sustainable tourism, attracting visitors interested in heritage and the environment and increasing tourism revenues for the region.

II- Conclusion:

Interventions in historic urban fabrics are complex and multifaceted challenges, where economic, social, and cultural aspects intersect. However,

this study presents a comprehensive vision for transforming this challenge into an opportunity. Ksar Sfisifa, with its historical and architectural value, is poised to become a beacon of sustainability, where the heritage of the past meets the innovations of the present.

By adopting innovative architectural and technical solutions, the authentic appearance of the Ksar can be preserved while providing it with clean, sustainable energy, ensuring its continuity as a cultural and economic resource for future generations. The success of such projects requires the concerted efforts of all stakeholders, from policymakers and researchers to engineers and local communities. By adhering to strict standards for heritage preservation, the desert Ksour can become living symbols of sustainable development, combining authenticity and innovation, and illuminating the path to a brighter future.

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