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Chapter 5: Techno-Economic Evaluation of a Solar Heating Project

V.1 Introduction:

The techno-economic evaluation makes it possible to determine the feasibility, profitability, and relevance of a heating system that uses solar energy. It combines technical analysis (thermal needs, collector performance, efficiency, etc.) and economic analysis (costs, energy savings, payback time, project profitability).

A project is considered viable when the energy performance meets the required demand and the investment becomes profitable within an acceptable time frame.

V.2 Technical Analysis

As part of the techno-economic evaluation of a solar heating project, the technical analysis represents the first crucial step in verifying the system's feasibility and ensuring its future performance. It involves accurately characterizing the space to be heated (geometry, insulation, orientation), estimating the thermal requirements based on heat losses and local climatic conditions, and sizing the components of the solar thermal system. This includes selecting the type and surface area of the collectors, the volume of the storage tank, hydraulic accessories, and control devices.

The technical analysis also makes it possible to evaluate the system's actual efficiencies, thermal losses, solar coverage periods, and any auxiliary heating needs. It therefore provides all the physical and operational parameters required to correctly estimate the useful energy production—an essential prerequisite before conducting the economic analysis and assessing the project's profitability.

V. 2.1. Assessment of Thermal Needs

The assessment of thermal needs consists of determining the amount of heat required to maintain a comfortable temperature inside a room or building. It is mainly based on calculating heat losses through the building envelope (walls, roof, windows, floor) and through air exchange, taking into account the temperature difference between the indoor and outdoor environments. Additional demand may be included when domestic hot water heating or peak load requirements are present. This analysis makes it possible to quantify the required heating power as well as the daily or seasonal energy needed, forming an essential step for properly sizing a solar heating system and ensuring its performance. The assessment of thermal needs begins with calculating the energy required to heat a room or a thermal process.

a) Heating of a Room

In the case of heating a room, the total thermal energy is determined using the following relation:

$$\mathbf{Q}_{\text{need}=\sum(\mathbf{UA})\times\Delta\text{T}\times\text{t}} \qquad \textbf{(1)}$$

UA: overall heat loss coefficient (W/K)

ΔT: indoor–outdoor temperature difference (°C)

t: duration (hours) during which heating must be provided.

This expression makes it possible to account for all losses through walls, windows, and air infiltrations.

b) Water Heating

For water heating, the thermal needs are evaluated using the following formula:

$$\text{Q} = \text{m} \times C_p \times \Delta\text{T} \qquad \textbf{(2)}$$

The equation (2) links the required energy to the mass of water, its specific heat capacity, and the imposed temperature rise. These two methods form the basis for sizing a solar heating system, as they allow for an accurate estimation of the energy demand to be met.

V. 2.2. Solar Resource

The assessment of the solar resource is a key step in the techno-economic study of a solar heating system. It is based on the analysis of the global solar radiation available at the site, generally expressed in kWh/m²/day, taking into account the orientation and tilt of the collectors in order to optimize solar energy capture. Local weather conditions, such as cloudiness, dust, or seasonal variations, also influence the amount of energy that can actually be harvested and must therefore be included in the analysis.

The solar energy received by the installation is then estimated using the following relation:

$$\text{E}_{\text{sol}} = \mathbf{G} \times \mathbf{A} \qquad \textbf{(3)}$$

Where **G** represents the global irradiation on the collector plane and **A** its surface area. This assessment makes it possible to determine the available solar potential to cover the system's thermal needs and guides the optimal sizing of the collectors.

2.3. Performance of Solar Collectors

The evaluation of solar collector performance is a key step in the study of a solar heating system, as it determines the amount of energy that is actually converted into useful heat. The efficiency of a collector depends mainly on the technology used—whether it is a glazed flat-plate collector or an evacuated tube collector—its thermal losses, the flow rate of the heat-transfer fluid, and the operating temperature of the system. These factors directly influence the collector's ability to transfer the received heat to the fluid.

The instantaneous efficiency can be estimated in a simplified manner using the following expression:

$$\eta = \boldsymbol{\eta}_0 - a_1(T_m - T_a)G - a_2(T_m - T_a)^2 \qquad \textbf{(4)}$$

Where $\boldsymbol{\eta_0}$ is the optical efficiency, $\mathbf{a_1}$ and $\mathbf{a_2}$ are the thermal loss coefficients, $\mathbf{T_m}$ is the mean fluid temperature, $\mathbf{T_a}$ is the ambient temperature, and **G** is the received irradiation. The useful energy produced by the collector is then given by:

$$\mathrm{Q_{usful}} = \boldsymbol{\eta} \times \mathbf{E_{sol}} \qquad \textbf{(5)}$$

This relation makes it possible to link the actual performance of the collector to the available solar resource.

3. Economic Analysis

3.1. Investment Costs (CAPEX)

Investment costs include all expenses required for the complete installation of the solar thermal system. They primarily consist of the price of the solar collectors, as well as the structure or mounting support used to fix them in place. Added to this are the costs related to the storage tank, hydraulic components such as the pump, heat exchanger, and control system, as well as the hydraulic circuit (piping, insulation, fittings). Finally, installation and commissioning fees represent a significant portion of the CAPEX.

The total investment cost is calculated as follows:

$$\mathrm{C_{invest}} = \sum_i \boldsymbol{C_i} \qquad \textbf{(6)}$$

Where each $\mathbf{C_i}$ represents the cost of a specific component or budget item.

3.2. Operating Costs (OPEX)

Operating costs cover expenses related to the use and maintenance of the system throughout its lifetime. They mainly include the electricity consumption of the circulation pump, annual maintenance required for proper system operation, as well as periodic replacement of certain parts, such as the pump or the heat-transfer fluid, which must be renewed after a few years. These costs are generally low compared to CAPEX but must be included for a comprehensive economic analysis.

3.3. Energy Savings

Energy savings correspond to the amount of conventional energy (gas or electricity) that the solar system helps to avoid consuming. Annual savings are calculated based on the useful heat produced by the installation and the price of conventional energy. They are expressed as follows:

$$\mathrm{E}_{\mathrm{eco}} = Q_{usful} \times P_{energy} \qquad \textbf{(7)}$$

Where $\mathbf{Q}_{(\mathbf{utile})}$ represents the thermal energy actually utilized by the user, and $\mathbf{P}_{(\mathbf{energy})}$ denotes the unit price of the reference energy. These savings allow for the assessment of the system's profitability over its lifetime, particularly through indicators such as the payback period.

4. Profitability Criteria

4.1. Simple Payback Time (Payback)

The simple payback time (SPT) estimates the duration required for the savings generated by the system to offset the total initial investment cost. It provides a quick and intuitive indicator of the project's profitability. The SPT is calculated by dividing the investment cost by the annual savings achieved, according to the following relation:

$$TRS = \frac{C_{invest}}{E_{eco}} \qquad \textbf{(7)}$$

Ainsi, un temps de retour court indique que le système devient rentable plus rapidement.

4.2. Valeur actuelle nette (VAN)

La valeur actuelle nette (VAN) est un critère économique plus complet, qui prend en compte l'actualisation des flux d'économies d'énergie et des coûts d'exploitation sur la durée de vie du système. Elle permet de déterminer si le projet génère une valeur économique positive lorsqu'on intègre la notion de valeur temporelle de l'argent. La VAN est calculée comme suit :

$$VAN = \sum_{i=1}^{N} \frac{E_{eco} - OPEX}{(1+i)^t} - C_{invest} \qquad \textbf{(8)}$$

Where **i** represents the discount rate and **N** is the system's lifetime, generally between 20 and 25 years. A positive NPV (NPV > 0) indicates that the project is economically viable and provides added value throughout its operational period.

4.3. Internal Rate of Return (IRR)

The internal rate of return (IRR) is the discount rate **i** at which the project's net present value becomes zero. In other words, it is the rate that exactly balances the discounted costs and benefits:

$$VAN = 0 \qquad \textbf{(9)}$$

The higher the IRR, the more profitable the project is considered. This criterion is particularly useful for comparing different investment projects or for evaluating the attractiveness of a solar system compared to other energy solutions.

5. Environmental Analysis

The environmental analysis allows for the assessment of the ecological benefits of a solar heating project. The use of solar energy for heating directly contributes to reducing CO_2 emissions by replacing conventional energy sources, such as gas or electricity produced from fossil fuels. It also promotes the development of renewable energies and supports the energy transition. Beyond the energy aspect, the installation of solar collectors improves the thermal comfort of occupants while generating a low carbon footprint once in operation, due to the absence of combustion or direct emissions. The avoided CO_2 emissions can be estimated using the following relation:

$$CO_2 = Q_{useful} \times f_{CO_2} \qquad \textbf{(10)}$$

Where $\mathbf{Q_{(useful)}}$ represents the thermal energy supplied by the system and $\mathbf{f_{(CO_2)}}$ is the emission factor corresponding to the type of energy being replaced. This assessment makes it possible to quantify the positive environmental impact of the project and strengthens the sustainability justification for the investment.

Conclusion

The techno-economic evaluation of a solar heating project is an essential step to ensure the feasibility, profitability, and sustainability of a system before its installation. The technical analysis determines the building's thermal needs, correctly sizes the collectors and storage, and optimizes system performance based on the available solar resource and site characteristics. The economic analysis completes the study by taking into account investment costs (CAPEX), operating costs (OPEX), and energy savings, using financial indicators such as the simple payback time, net present value, and internal rate of return to measure project profitability. At the same time, the environmental analysis highlights the positive impact of solar heating on reducing CO_2 emissions, promoting renewable energy, and improving thermal comfort, while generating a low carbon footprint after installation. Integrating these different dimensions allows for informed decision-making, comparison of alternative solutions, and ensures that the project is not only economically viable but also environmentally responsible, thus contributing to sustainable energy development.