

Solar panels overheating protection: a review

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ABSTRACT

Reduced energy consumption is a direct result of building optimization. Solar panels and heat detectors can provide the necessary power. After years of refinement and development, methods for regulating solar panels' output are finally finding their way into everyday life, where they are having a dramatic impact on the foundations of sustainability. This document provides an up-to-date assessment of several strategies for preventing solar panels from overheating, all of which serve to boost their efficiency and prolong their service life. It begins with a brief background on protection technologies before moving on to a survey of recently filed patent applications that address this topic. The study concludes with a proposed assessment of the strengths and shortcomings of these safeguards. We anticipate that the information included in this review paper will be an invaluable tool for scholars and researchers.

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1. INTRODUCTION

Today, solar energy is one of the most promising sources to meet the world's energy needs. This energy has the advantage of being clean and renewable, and Morocco is classified as one of the most promising countries in solar energy. The best time for solar panels is in summer. This is where they generate the most energy. But it's also the time of year when people go on vacation and leave their homes unoccupied. Solar collectors suffer from this major problem which is the phenomenon of overheating. Therefore, it's prudent to consider the risks and difficulties related to overheating in thermal and photovoltaic panels. We know that conventional thermal panels may reach temperatures of up to 150 °C. There is no domestic hot water draw when the house is empty, for example, for showers. As a result, the thermal panels are not mechanically cooled. Then, they are vulnerable to overheating issues on some installations, which might lead to significant mechanical loads on joints and pipework and circuit obstruction. The heat transfer fluid inside the panel can boil and vaporize. This produces an expansion and, as a result, an overpressure, which the expansion vessel absorbs. If this vessel is poorly built, the installation will fail because of the overpressure when the heat transfer fluid boils and turns to gas. However, the gas expands with less effort. A solar panel installation will be needed to help with draining, recycling, and replenishing the glycol fluid. The mechanical parts of the solar installation can deteriorate if it becomes too hot, which might lead to the system failing altogether. heated thermal solar panels pose risks to the overall system and are expensive to replace. Numerous approaches may be taken to prevent the solar panel from getting too hot. One example is the hybrid solar panel. Its stagnation temperature

is a significant technical advantage over traditional thermal solar panels. The stagnation zone has a comfortable temperature. The maximum temperature, when not integrated, is 70 degrees. This uniqueness results from technical decisions while developing a hybrid solar collector. Recent studies by Gao *et al.* [1] have shown the significance of form-stable, mineral-based phase transition materials for thermal energy storage. Overheating self-protection features have also been the topic of research by Li *et al.* [2]. They demonstrated a self-protecting method against overheating that makes organic cathode materials for lithium batteries safer. To improve cycle stability and overheated self-protection, they provided $\text{LiNi}_0.8\text{Co}_0.1\text{Mn}_0.1\text{O}_2$ cathode materials with a temperature-responsive coating [3]. In the interest of sustainable development, new methods of optimizing energy consumption [4] and integrating energy efficiency systems [5] were invented to ensure the comfort of human beings. Indeed, energy administration can reduce primary energy consumption, extend the life of powerful production equipment, reduce greenhouse gas emissions, cover energy needs, and meet demand in [6]-[9]. The function of energy production in efficient-energy systems using solar energy as daylight [10], useful heat, and electricity requires a transformation in the way solar panels are designed and operated to be cost-effective and affordable. Overheating is the primary obstacle solar panels must overcome in our study. In this paper, we examine the strategies that protect solar panels against the phenomena of overheating in order to determine the pros and cons of each kind. In addition, we will identify a new viable study field as the primary goal of this investigation.

2. METHODS

2.1. Autonomous systems for protecting solar collectors against overheating

Overheating happens when the solar energy absorbed by the solar water heater surpasses the thermal capacity of its principal heat transfer fluid circuit [11], this results in high absorber temperatures. Similarly, it is found when circumstances are adverse for solar panels. It can be encountered on a solar installation during periods of strong sunshine for at least two main reasons: When the recovered solar energy is no longer transmitted to the solar storage volume, in case of pump failure, clogging of the exchanger, or simply a power failure; or when the recovered solar energy is not consumed, in case of an unoccupied period of the building, or of over-dimensioning of the solar installation for example.

Solutions were presented in the 2020s by Hajji [12], it's part of the theory and practice of variable structure systems whose principal aims are to protect solar panels from overheating. This is an automatic system that plays a double role: the protection of solar collectors against overheating and dust. This system uses a blind that goes up and down depending on the conditions. This system increases the efficiency of the solar collector and extends its life. To highlight the effect of overheating on a PV collector, a modeling of the solar water heater in the case of stagnation using MATLAB/Simulink was done. Based on our literature review in [11]-[13], we can conclude that this autonomous protection system has an excellent performance in terms of adaptability to different weather conditions. However, this solution has some shortcomings such as the complexity due to the over-parameterization and the inaccurate estimation of the maximum heat limit of the system components.

2.2. Self-draining solution

When the solar thermal system is designed for space heating and solar water heaters production. The risk of overheating collectors is important in summer. It consists in draining the solar collectors of the heat transfer fluid as soon as no heat is required. To achieve this, a recovery bottle must be installed. The latter is only partially filled. The available space allows the heat transfer fluid to be recovered from the collectors as soon as the pump stops working. As soon as there is a need for heat, the pump starts up again and the collectors are filled with fluid again (Figure 1).

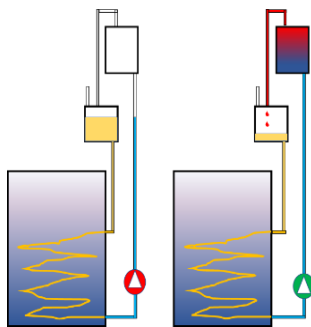


Figure 1. The operation principle

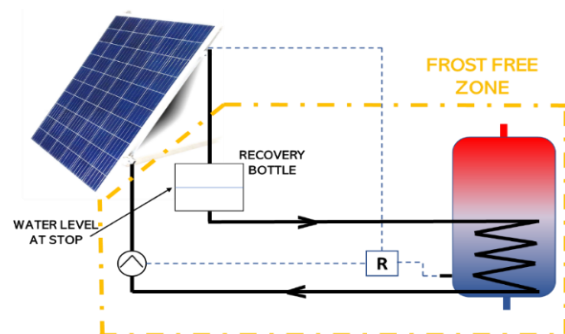


Figure 2. The expansion tank position

The phenomenon of stagnation is no longer possible. The system does not overheat. Therefore, the expansion tank is not necessary (Figure 2). Wenisch G. presented a new method for automatically controlling the draining of a self-draining thermal solar plant. For function testing of a solar installation, the device involves the collectors during periods of overheating or frost risk discharging automatically into a collection container. During the emptying phase by-passing the collectors, a flow component was used, permitting a circulation only in the overheating/frost-free area in a connecting conduit from the collector backflow to the collector forward flow. A separate hand-operated switch for function testing in the regulating apparatus acts on the flow component and the circulating pump. This switch acts as a time switch for the automatic switch-off after completion of the function test [14].

Savariaux *et al.* [15], the solution involves introducing a fixed volume of heat transfer fluid into an installation. The dynamic flow of the fluid circulating in an outgoing circuit is measured. Measurement is performed until the end of energy production by a solar collector. Flow and time of flow of the fluid from the collector in the direction of a buffer tank are measured when the production is stopped. The volume of liquid flown out of the collector is compared with the initial volume of fluid introduced into the installation, and corrective actions are performed if the liquid volume is less than the initial volume. An independent claim is also included for a self-drainable solar thermal installation.

2.3. Thermodiode system

A thermodiode device can relieve solar heating issues in the summer [16]. The bidirectional thermodiodes invented by Chun *et al.* can minimize solar heating in the summer and capture solar energy as heat in the winter [17]. The design, construction, and testing of a novel bidirectional thermodiode for energy-efficient buildings have been completed. For applications involving solar heating, experimental results are provided and disputed.

The thermodiode system comprised of numerous water-filled rectangular loops. For operations in both directions, the tilting angle of the loops can be altered to reverse the natural convection inside the loops. Horizontal parts of the loops were fastened to metallic panels facing either the interior or outside. By rotating the panels or putting a detachable shade device in front of the surfaces, the quantity of heat radiation striking the surfaces facing the outside may be controlled. The indoor investigations for the thermodiode's use in the winter indicated that it takes between 7 and 20 minutes for natural convection to develop throughout the loops. Before the throughflow commenced, the fluid in the heated copper tubes had attained maximum temperature.

This temperature decreased immediately after the beginning of throughflow and then regained [18]. Eventually, temperatures on the thermodiode rose at approximately the same rate at different locations until a steady state was reached. During the cool-down phase, the temperatures fell at the same rate without humps, showing that only conduction occurred in the rectangular loops when the thermodiode was reverse-biased. Chun *et al.* [16], devised a simple analytical model to evaluate the diode system's temperature changes and heat transfer rates. Forward biasing the diode approximately multiplies the heat transfer rate for incoming radiation of 600 W/m² by a factor of 100. In the context of research for the development of modern technologies based on innovative methods, Prismatic structures have received immense interest from researchers and industrialists since 1999. The work of Slamam M. and Griessen R. presents a relevant method of solar collector overheating protection [19].

2.4. Highly efficient thermal solar collector overheating protection: innovative smart selective coating

High-efficiency solar thermal systems often experience stagnant conditions where solar panel temperatures can reach as high as 190-200 °C [20]. One of the most common issues with solar thermal systems is stagnation, which leads to evaporation and glycol deterioration, decreased performance, and more frequent maintenance and repair expenditures. With the help of a novel intelligent selective coating, which exhibits a dramatic rise in infrared emissivity (thermochromic effect) at the crucial temperature, the stagnation temperature may be lowered to just 150 °C. Light intensity is 1000 W/m² and the temperature is 35 degrees Celsius outside [20]. Because of the new smart selective coating's high solar absorption coefficient (>94%) and low emissivity (6%) at low temperatures, and because the thermochromic effect only becomes noticeable once the temperature rises to about 70°C, the high performance of the new thermochromic thermal solar system serves as an excellent example of the effect of using the smart selective coating. Hot water production relies on how well the system performs. The composition, structure, and optical characteristics of a new generation of selective coatings based on Vanadium and Alumina mixes (VO₂/VnO₂n₁/Al₂O₃/SiO₂) were described in [20]-[21]. Above 70 degrees Celsius, emissivity dramatically increased, as seen in FTIR (Fourier Transform Infrared) spectroscopy and infrared camera photos. The new generation of thermochromic solar panels was shown to have a minimum lifetime of 25 years even after being exposed to aging behavior (high temperatures, humidity, and temperature swings).

2.5. Usage of supercritical fluids in parabolic solar collector

Due to its capacity to function at greater temperatures than thermal oil, which restricts the overall efficiency of a thermodynamic cycle, researchers are investigating the use of supercritical fluid in parabolic solar collectors. An investigation on the usage of different supercritical fluids in parabolic trough solar collectors was detailed in [22]. Zaharil [22], examined and studied the performance of three distinct supercritical fluids, namely water nitrogen and Sulphur hexafluoride. The commercial software EES was used to construct, validate, and solve a 1-D mathematical model. At common inlet temperatures, the results demonstrated that water outperforms the other fluids in terms of energy performance. At an inlet temperature of 477 °C, all fluids showed maximum energetic efficiency, with 46.46%, 46.24%, and 45.76% for Water, Sulphur hexafluoride, and Nitrogen, respectively [22]. Because water has a thermal storage energy density of roughly 165% higher than the greatest value of molten salt, it is the best supercritical fluid for use in thermal storage at 377 °C, according to a comparison of various supercritical fluids [22].

2.6. Usage of nanofluids in solar thermal collectors

Most solar collectors have the potential to improve overall efficiency using nanofluids [23]-[26]. To highlight the effect of using nanofluids on solar thermal collectors, modeling of this product in a numerical simulation was done. The impact of various nanomaterials on the efficiency of solar collectors was discussed in [27]-[28]. Wole-Osho *et al.* [27], cover the constraints of using nanofluids in solar collectors and the long-term difficulty of doing so. Most solar collectors have the potential to improve overall efficiency using nanofluids. However, the full promise of nanofluids in heat transfer applications will not be realized until some of the problems about hysteresis, stability, and overall predictability of nanofluids were answered. One of the problems with numerical modeling of nanofluids as heat transfer fluids in collectors. The thermophysical parameters of the heat transfer fluid are used in collector flow models. Consequently, any mistakes in the nanofluid thermophysical property model would lead to inaccuracies in estimating the collector's flow and heat transfer [29]-[31]. Photovoltaic and thermal collector PV/T technologies have gotten a lot of interest because they solve the problem of unwanted overheating of solar cells [29]-[31]. These systems are designed to transport heat away from photovoltaic cells, allowing them to cool and increase efficiency by lowering resistance [32]-[35].

2.7. Application of artificial intelligence against overheating of solar panels

To increase the efficiency of solar panels, cooling is an important element, the efficiency of which can be enhanced by artificial intelligence. Artificial intelligence (AI) is a set of algorithms that provide a computer with both analytical and decision-making capabilities, allowing it to intelligently adapt to situations by making predictions based on previously collected data. Today, several studies are looking at integrating AI into solar power systems to protect them from overheating.

Artificial intelligence approaches can provide better, faster, and more practical forecasts than any other method. AI consists of several branches such as artificial neural network (ANN), fuzzy logic (FL), adaptive network-based fuzzy inference system (ANFIS), and data mining (DM) [36]. The optimization of each solar panel according to the time of day and its geographical location is a method to take into account the atmospheric variations in the design of solar cells to produce more energy. It includes in the calculation of solar power generation systems all the variations of the solar spectrum to predict the production of solar photovoltaic energy by:

- Using a statistical and artificial intelligence technique called clustering [37];
- Boosting solar radiation predictions with global climate models, observational predictors, and hybrid deep-machine learning algorithms [38];
- Accurate thermal prediction model for building-integrated photovoltaics systems using guided artificial intelligence algorithms [39];
- Improving the efficacy of diagnosis and remote sensing of solar photovoltaic systems [40].

There are several optimization methods using artificial intelligence algorithms to estimate the energy efficiency of solar panels [41]. We can mention that using AI techniques can guarantee autonomous protection against overheating for solar panels of new generations.

3. RESULTS AND DISCUSSION

Based on our review, we screened several journal articles and selected 50 articles from over 100 evaluated scientific documents including all the proceedings, which contained qualitative information about solutions for the protection of solar panels from overheating. Very few of the articles explicitly explored the autonomous protection system of solar collectors against overheating. Furthermore, several studies were

investigated. Consequently, we had to include studies that are only part of reducing the impacts of stagnation [42]-[44]. Some of those methods offered aren't appropriate for all system designs and situations. Furthermore, the expense of anti-stagnation measures should be reduced, and passively functioning systems, which do not rely on user or controller intervention or needs extra power to operate, appear to have considerable durability advantages.

In general, techniques for stagnation control differ by climate and were influenced by other system design factors like freeze security solutions, system design temperatures, collector type, and loads. The most important thing that was learned from this analysis was the need of having protective measures against overheating to ensure that installations would last for a significant amount of time [45]-[46]. It had a substantial influence on a number of the experiments, but when we compared them, we discovered that the connection between overheating and the style of installation is not necessarily an obvious one. The concept of gaining knowledge from the experiences of others was one that was discussed in a number of articles, and the significance of support groups and other networks was emphasized [47]. Nevertheless, the research conducted by Jun *et al.*, described the structure of the solar/photovoltaic hybrid system to prevent overheating and improve system performance. This also appears to be applicable to synchronous motors using wavelets packets [48]-[49]. This study's findings also emphasize the need to use wavelets [50]-[52], integrated with data analysis techniques often employed in biomedical signal processing, such as ICA-NMF-SVD-PCA [53], [54] to further improve the aforementioned techniques' efficacy.

This could be an important area to investigate further regarding the scarcity of water in particular sites and hybrid mechanism energy production. In addition, it is demonstrated that the incorporation of solar energy concerns into the urban design is essential for the development of low-carbon cities. Akrofi and Okitasari [55] recognize the validity of the processual view in their own study.

4. CONCLUSION

This qualitative systematic review has analyzed the literature on the overheating protection of solar panels with a focus on photovoltaic, thermal, and hybrid systems to produce renewable energy. Several important issues about the heating mechanism and the stagnation problem that might lead to the installation's destruction were found in the review. The good news is that numerous viable alternatives were also uncovered. More in-depth studies would be welcome additions to the rather limited body of literature on the experiences of development of various methods in follow-up, especially if they explicitly explore perceptions and experiences for protecting solar panels against overheating and carefully analyze these particular situations. Despite the remarkable advantages of several methods, we notice the deficiency of solutions that consider not only the phenomenon of overheating but also the protection against freezing. The scarcity of water leads us to think about other responsible solutions to produce electricity. The extension of our work is to introduce these problems, which is one of our main concerns in this research paper. Moreover, Cost reduction and durability enhancement of solar protection systems through the application of new components and materials have been and remain the main challenges of research interest. Therefore, the use of AI techniques can guarantee autonomous protection against overheating for solar panels.

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