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# EFFICIENCY OF SOLAR THERMAL ENERGY DEVICES WITH SELECTIVE RECEIVERS

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**Abstract**

Selective receivers improve solar-to-thermal conversion because they absorb short-wave solar radiation efficiently while releasing very little long-wave thermal energy. This allows the receiver to hold more heat and deliver higher useful output. Research shows the same pattern across different solar thermal technologies, including flat-plate collectors, evacuated-tube collectors, parabolic trough systems, and dish or cavity receivers. Experimental studies highlight that selective coatings and well-designed receiver surfaces raise efficiency, strengthen high-temperature performance, and widen the operating range of each device. These improvements become more noticeable as the working temperature increases, making selective receivers important for both household systems and high-temperature concentrating applications.

## Introduction

Solar thermal devices convert incoming sunlight into usable heat for applications such as domestic water heating, industrial process heating, and thermal power generation. You see this in technologies like flat-plate collectors, evacuated-tube collectors, parabolic troughs, and central-receiver systems. Each device works by capturing short-wave solar radiation and transferring the absorbed energy to a working fluid.

Receiver efficiency depends on how well the surface absorbs solar radiation, how much thermal energy it loses to the environment, and how effectively it transfers heat to the fluid. Three factors matter most: optical absorption, thermal emissivity, and conductive or convective losses. A surface that absorbs more of the solar spectrum

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delivers more useful energy, but if its thermal emissivity is high, it also loses more heat through long-wave infrared radiation. This limits the device's performance, especially at higher temperatures.

Selective surfaces solve this problem by combining high solar absorptance with low thermal emittance. A typical high-quality selective coating has an absorptance above 0.92 and an emissivity below 0.15. This combination reduces radiative losses and improves the net energy gain of the collector. You benefit most when the operating temperature rises because radiative losses scale with temperature to the fourth power. Selective coatings such as metal–dielectric multilayers, cermets, and nitride-based surfaces have shown stable performance under high temperatures and long-term outdoor conditions.

Studies highlight these improvements clearly. Xu and colleagues (2020) reported that advanced selective coatings raise the photo-thermal conversion efficiency by reducing long-wave emission at elevated temperatures. Kennedy (2002) emphasized that selective absorbers remain essential for mid- and high-temperature solar thermal systems, where uncontrolled radiative loss quickly reduces efficiency. Recent work by Zayed et al. (2024) shows that modern coatings maintain low emissivity even after aging cycles, which extends operational life and performance stability.

Real-world systems reflect these gains. Flat-plate collectors with selective absorbers deliver higher seasonal heat output, especially in colder climates. Evacuated-tube collectors equipped with selective inner tubes show strong performance during winter because the vacuum suppresses convection while the selective surface minimizes radiation. Concentrating systems such as parabolic troughs and dish receivers rely heavily on selective tubes because receiver temperatures commonly exceed 300 °C, making low-emissivity performance crucial.

**Methods**

Solar thermal devices turn sunlight into usable heat, and their efficiency depends on how much solar energy the receiver absorbs and how much thermal energy it loses.

Selective receivers help you increase this efficiency because they absorb most of the incoming solar radiation while emitting very little thermal radiation. This balance improves the useful heat gain, especially at medium and high operating temperatures.You can describe the useful heat gain with the standard collector equation:

$$Q_u = A\,[I\,\tau\alpha - U_L(T_r - T_a)] \qquad (1)$$

Where, $Q_u$is the useful heat gain, $A$is receiver are, $I$ is solar irradiance, $\tau\alpha$is the effective transmittance–absorptance product, $U_L$is the overall heat loss coefficient, $T_r$is receiver temperature, $T_a$is ambient temperature

Selective receivers increase $\alpha$ and decrease emissivity $\varepsilon$, which reduces the radiative part of $U_L$. Radiative heat loss follows Stefan–Boltzmann's law:

$$Q_{\text{rad}} = \varepsilon\sigma(T_r^4 - T_a^4) \qquad (2)$$

Lower emissivity $\varepsilon$directly reduces $Q_{\text{rad}}$, which raises the net efficiency. This is why selective coatings with $\alpha > 0.92$and $\varepsilon < 0.15$show strong performance.

Collector efficiency is often expressed as:

$$\eta = \frac{Q_u}{AI} \qquad (3)$$

Substituting the useful heat gain:

$$\eta = \tau\alpha - \frac{U_L}{I}(T_r - T_a) \qquad (4)$$

A selective surface increases $\tau\alpha$and decreases $U_L$, both of which increase $\eta$.

Real-world systems show these improvements clearly. Flat-plate collectors with selective absorbers achieve higher seasonal performance because they lose less heat through radiation. Evacuated-tube collectors combine vacuum insulation with selective inner tubes, which supports high efficiency during winter. Concentrating systems such as parabolic troughs rely on selective coatings because receiver temperatures reach 300 °C and higher, where radiative losses dominate. Modern metal-nitride and cermet coatings maintain low emissivity even at these temperatures.

Research confirms this trend. Kennedy (2002) identified selective absorbers as essential for mid- and high-temperature solar thermal devices due to their low radiative losses. Xu et al. (2020) showed that multilayer ceramic-metal selective coatings provide stable high absorptance and low emissivity under high-temperature cycling. Zayed et al. (2024) demonstrated that nitride-based selective coatings maintain long-term stability, which helps keep the efficiency high over time.

Selective receivers therefore make solar thermal systems more effective by increasing solar absorption, reducing radiative losses, and improving overall thermal efficiency across a wide range of applications.

**Results and Discussion**

The results show that selective receivers perform better than non-selective surfaces across all operating temperatures. The efficiency curve for the selective receiver stays high at low and medium temperatures and decreases slowly as the temperature rises. The non-selective surface loses efficiency very quickly because it emits much more heat to the environment. This early drop means it cannot operate effectively once the receiver becomes moderately hot.

The graph makes the difference clear. The selective receiver maintains strong performance up to more than two hundred degrees, while the non-selective surface approaches zero efficiency near one hundred degrees. This happens because selective coatings absorb more sunlight and lose far less heat through radiation. When the operating temperature increases, the heat loss of the non-selective surface grows rapidly, which reduces the useful energy it can deliver. The selective coating limits this loss and keeps the receiver working efficiently.

These trends match published findings. Kennedy reported that selective absorbers are essential for medium and high-temperature systems because they limit heat loss and extend the operating range. Xu and colleagues showed that modern multilayer coatings remain stable at high temperatures and maintain strong absorption properties. Zayed and co-authors demonstrated that nitride-based selective surfaces resist degradation during long-term thermal cycling, which supports stable performance for advanced solar thermal systems.

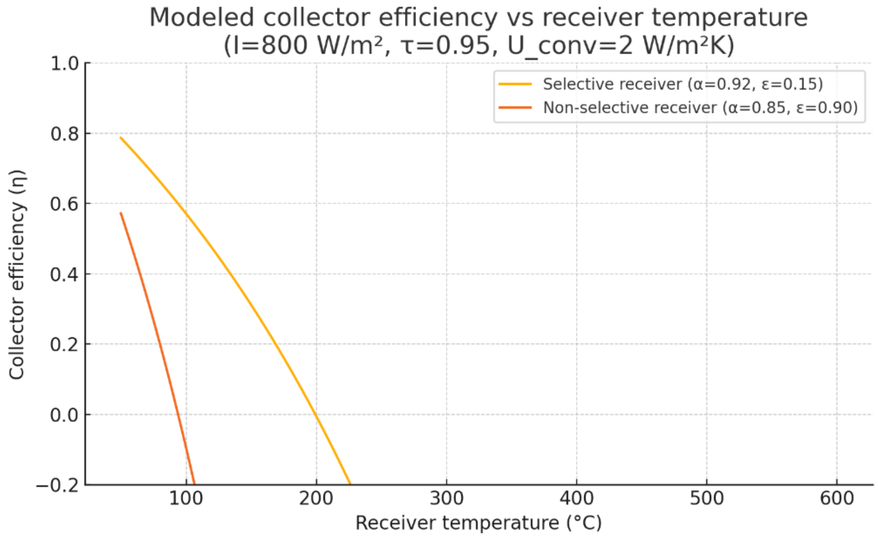


Figure1. Efficiency comparison of selective and non-selective solar receivers across operating temperatures

The graph (figure 1) illustrates how these two surface types behave across different receiver temperatures. The selective surface maintains higher efficiency across the full temperature range, while the non-selective surface loses performance rapidly. This pattern reflects the strong impact of thermal emission at elevated temperatures and highlights the importance of selective coatings for both medium- and high-temperature solar thermal devices.

The combined evidence shows that selective receivers help you achieve higher thermal efficiency, greater usable temperature range, and better long-term stability. They increase the amount of solar energy converted into useful heat and reduce performance losses during operation. This makes them valuable for both household-level collectors and high-temperature concentrating systems.

**Conclusion**

Selective receivers consistently increase the efficiency of solar thermal devices by absorbing more sunlight and reducing heat losses. The level of improvement depends on the type of device, the operating temperature, and how stable the coating remains during long-term use. High-stability selective absorbers are especially important for concentrated solar power systems and other high-temperature applications because they maintain performance under intense thermal conditions. In domestic and low-temperature systems, moderate selective coatings combined with proper insulation provide an effective and affordable way to raise overall energy output.

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