# EFFICIENCY ANALYSIS OF FLAT PLATE COLLECTORS FOR BUILDING FAÇADE INTEGRATION

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## ABSTRACT

A theoretical approach has been used to evaluate the performance of facade integrated solar collectors based on the physical collector parameters such as absorber plate absorptance, transmittance of the glazed cover plate and insulation thickness. A 1D steady state model, based on the Hottel Whillier Bliss equation, was employed to determine the effect of changing parameters to meet façade integration criteria.

*Keywords: Solar thermal, building integration, flat plate collectors*

## FACADE INTEGRATED FLAT PLATE COLLECTORS

Buildings account for 40% of the final energy consumption in Europe [1], Over half of this energy use is associated with building heating, cooling and domestic hot water (DHW) demands [2]. This energy is predominantly provided through the burning of fossil fuels, which can be reduced through the implementation of renewable energy systems. Solar thermal systems, for building applications, make use of an area on the building's envelope to install the solar collectors, which in turn, absorb the solar radiation and convert it to useful heat for the building's heating applications. These solar collectors are usually mounted on the roofs of buildings; however, a limited roof area and a high heating load may require the area of the façade to house these collectors [3]. Architectural integration barriers can become significant when the façade is used to house the collectors.

Solar thermal collectors may be categorised as Unglazed Collectors (UC), glazed Flat Plate Collectors (FPC) or Evacuated Tube Collectors. The FPC is Europe's most popular collector, accounting for 85% of the market share [4]. They consist of an absorber plate with a high absorptance and conductivity, insulated at the back using standard insulating wool or foam and insulated at the front through the use of a transparent cover (typically glass) which provides an air gap between the absorber and cover layer. A 1D steady state mathematical model, based on the Hotel Whillier Bliss equation [5], is used to examine the performance of FPC where the parameters are altered as appropriate for façade integration.

## STEADY STATE MODELLING METHOD

The underlying equations for developing the 1D steady state model are based on the following. The instantaneous efficiency, $\eta_i$, is used to compare the performance.

$$\eta_i = \frac{Q_u}{A_c G_T} \tag{1}$$

Where $A_c$ is the area of the collector ($m^2$) and $G_T$ is the solar irradiance on a tilted surface. The theoretical performance of the solar collector is determined using the Hottel-Whillie-Bliss relationship for the useful energy gain, $Q_u$:

$$Q_u = A_c F_R [G_T(\tau\alpha) - U_l(T_{f,i} - T_a)] \tag{2}$$

Where, $F_R$ is the heat removal factor, *(τα)* is the transmittance-absorptance product, $U_l$, is the total heat transfer coefficient, $T_{f,i}$ is the fluid inlet temperature and $T_a$, is the ambient temperature. $U_l$ is found by summing the heat lost through the top, $U_t$, the bottom, $U_b$, and the edges, $U_e$, of the collector. The top heat loss, $U_t$, is temperature dependent, thus, an iterative process is required to obtain the solution.

The heat removal factor, $F_R$, is included to allow for the assumption that the plate of the collector is at the inlet fluid temperature, $T_{f,i}$, rather than the actual mean plate temperature, $T_{p,m}$. The inlet fluid temperature is used since the mean plate temperature is difficult to accurately quantify using experimental methods [5]. Rearranging Equations (1) and (2) gives the following:

$$\eta_i = F_R(\tau\alpha) - F_R U_l \left( \frac{T_{f,i} - T_a}{G_T} \right) \tag{3}$$

The instantaneous thermal efficiency, $\eta_i$, can be plotted against the reduced temperature difference, *((Tf,i - Ta)/G)*, to determine the collectors performance. Since the top heat loss $U_t$, is temperature dependent, the relationship is non-linear. The subsequent section of this paper will use this model to plot the efficiency curves of various FPCs.

## RESULTS AND DISCUSSION

The model was used to compare the effect of altering three of the primary components of a FPC, cover, absorber and insulation. A standard FPC, with defined parameters (Table 1.) is used as a benchmark. The values used are typical of a FPC [5]. Parameters that are altered as a result of façade integration (highlighted with a **bold** font) will be varied and the resulting efficiency curves can be compared.

| Parameter | Value |
|---|---|
| *W* (distance between tubes) [m] | 0.15 |
| *D* (Tube diameter inside) [m] | 0.01 |
| $\delta$ (sheet thickness) [m] | 0.0005 |
| $k_a$ (absorber conductivity) [$Wm^{-1}K^{-1}$] | *385* |
| $h_{fi}$ (convective heat transfer) [$Wm^{-2}K^{-1}$] | 300 |
| $\dot{m}$ (flow rate) [$kg\ s^{-1}$] | 0.03 |
| $C_p$ (heat capacity) [$Jkg^{-1}K^{-1}$] | 4190 |
| **$\tau$ (cover transmittance)** | **0.94** |
| *G* (solar irradiance) [$Wm^{-2}$] | 1000 |
| **$\alpha$ (absorber absorptance)** | **0.95** |
| *N* (number of glass covers) | 1 |
| $\varepsilon_g$ (emittance of glass) | 0.88 |
| **$\varepsilon$ (emittance of plate)** | **0.95** |
| $h_w$ (wind) [$Wm^{-2}K^{-1}$] | 10 |
| $\beta$ (tilt angle) | 90 |
| $\sigma$ (Stefan boltzman constant) [$Wm^{-2}K^{-4}$] | 5.67037E-08 |
| **$L_b$ (back insulation thickness) [m]** | **0.05** |

*Table 1: Design Parameters and benchmark values of a flat plate collector*

### Cover

One way of achieving architectural integration is by providing a range of colours. Either the absorber plate or the glass cover may be coated to provide a colour that will fit in with the aesthetic of the building. An ideal cover would have a maximum transmittance, $\tau$, value. However, the introduction of colour to the glass cover of a FPC decreases the transmittance value. Work has been conducted on reducing the negative effect of colour on the efficiency of the collector by using thin film layers to produce a colour that is opaque to the human eye (large reflectance in the visible spectrum, $R_v$), but high transparency to solar energy (large solar transmittance). The idea was proposed by Schüler et al. [6] and then followed up by a number of simulation and experimental studies using different film deposition methods. The efficiency curves for two multilayered coloured coatings are displayed in Figure 1.

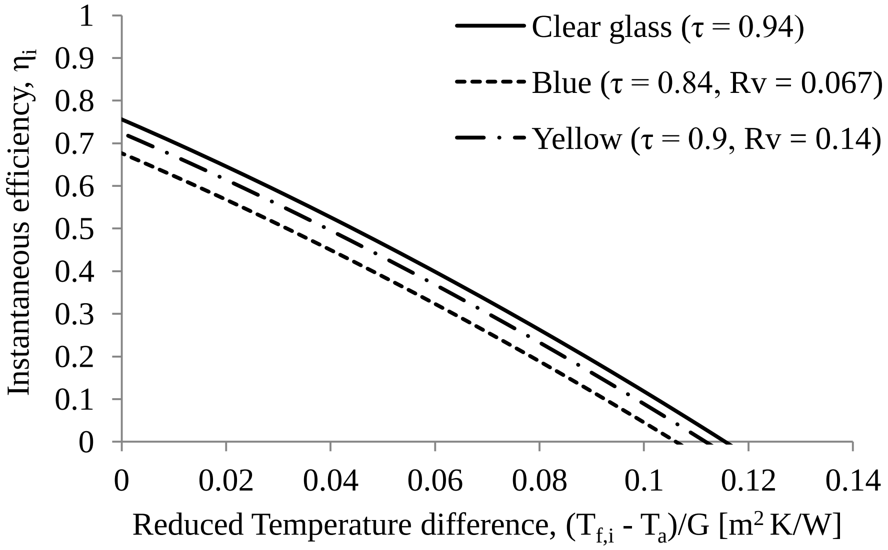


*Figure 1: Theoretical efficiency of FPCs with different cover colours (layer properties [7]).*

Depending on the number of layers, the refractive index of each layer and the thickness of each layer, a different colour with a different transmittance and visible reflectance would be achieved..

This study investigates how these property alterations affect the performance of a solar collector. Both the blue and yellow coloured thin films have a lower efficiency than that of clear glass, as expected. The thin films are made up of silicon and titanium oxide layers with different thicknesses to achieve these colours. In this case the yellow coloured collector outperforms the blue collector in terms of efficiency. The addition of these yellow and blue layers reduces the efficiency of this collector by 3% and 8% respectively.

**Absorber**

An alternative approach is to change the colour of the absorber plate. The absorber plate of a solar thermal collector is typically coated with a dark coating that has a high absorptance, $\alpha$. As with colour coating the cover of a FPC, a reduction in performance is also associated with colouring the absorber [8]. Tripanagnostopoulos et al. [9] used booster reflectors adjacent to the absorber to make up for this reduction in absorptance. To obtain a higher efficiency, spectrally selective coatings may also be applied [10], which have a absorptance, $\alpha$, for wavelengths between 0.3 and 2.5 μm and a low emittance, $\varepsilon$, for wavelengths greater than 2.5 μm.

The properties of concern for this study are the absorptance, α, and the emittance ε. By adjusting the outlined parameters and applying the model, efficiency curves are produced for three spectrally selective coatings, one black [8] and two alternative colours [11], as well as one non-spectrally selective coating [9]; displayed in Figure 2.

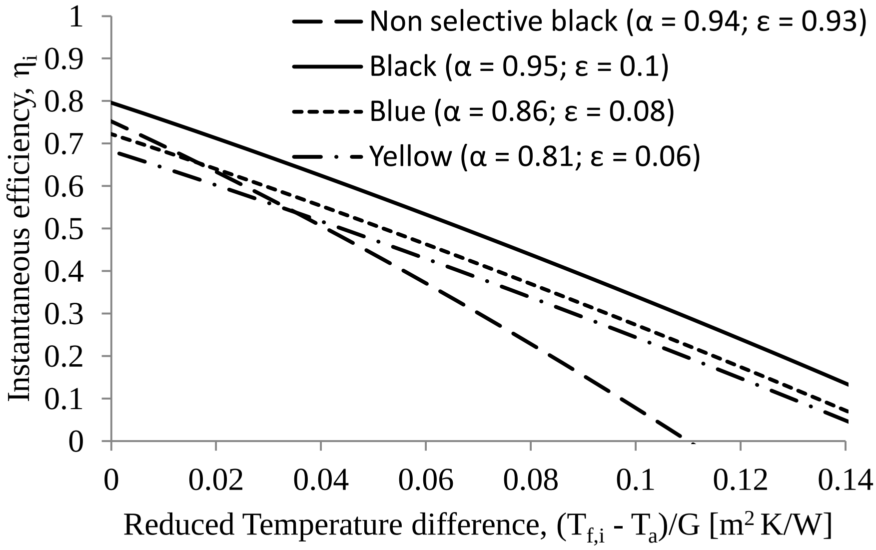


*Figure 2. Theoretical efficiency of solar collectors with different absorber colours & spectral selectivity.*

The spectrally selective coatings outperform the non-spectrally selective coatings since the emissivity is reduced, reducing the radiative heat losses, particularly as the temperature of the collector increases. A blue and yellow colouring are used again, however, the blue out performs the yellow; this can be attributed to its darker colour and hence higher absorptance. At a low reduced temperature difference (0.01 $m^2K/W$) the efficiency is reduced by 7% and 11% by changing to the referenced blue and yellow coating respectively; as the reduced temperature difference increases (0.14 $m^2K/W$) the reduction in efficiency becomes 6% and 9% respectively.

## Insulation

The back insulation thickness of a FPC ranges from approximately 0.04 to 0.075 m [12], offering product U-values of between 0.75 $W/m^2K$ and 0.42 $W/m^2K$ (assuming an insulation conductivity of 0.03 W/mK [13] ). However, for facade integrated collectors, a thicker insulation layer is required to ensure the envelope abides by building regulation specified U-values.

An insulation thickness of approximately 140 mm would be required to achieve a wall U-value of 0.21 $W/m^2K$ (this is the current standard for the UK and Ireland [14]). On the other hand, considering the high temperature reached by the absorber plate, the resultant radiating heat to the interior space can promote overheating if not appropriately insulated [15] [16]. A negligible increase in the internal temperature of less than 1K has been observed for a variety of wall systems with integrated collectors. The insulation applied to the back of the collectors is used to reduce the heat loss. Figure 3 shows how increasing the insulation at the back of the collector increases the performance, by reducing the heat loss.

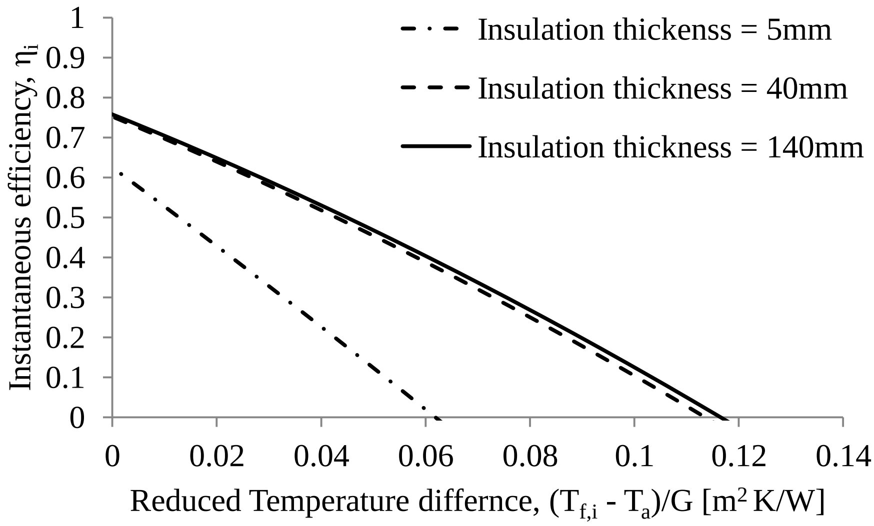


*Figure 3. Theoretical efficiency of solar collectors with different back insulation thicknesses.*

The results show how an increase in efficiency of no more than 2% is gained by increasing the thickness of insulation by more than 40 mm (typical insulation thickness). The convergence suggests that after 40mm of insulation the majority of the heat is lost through the top of the collector. However, for a facade integrated collector the insulation is also reducing the heat lost from the building's interior, therefore, justifying the increased thickness.

**CONCLUSION**

The performance of façade integrated flat plate collectors have been evaluated with reference to colouring the absorber and the cover and changing the thickness of the insulation. The effect of integrating a collector into the facade of a building on the efficiency of the collector is, therefore, presented.

It was found that for the colours compared in this study that colouring the glass cover will reduce the performance with the yellow cover considered in this paper having a 5% greater efficiency than that of the blue cover. On the other hand colouring the absorber plate yellow resulted in a lower efficiency than a blue coated absorber, by 2-4%. The effect the insulation's thickness had on the performance of the FPC, perceived for facade integration, was also addressed. The model showed that increasing the thickness past 40 mm resulted in no significant increases in the efficiency, however, if integrated into the facade of a building this would help reduce the unwanted heat losses or gains to the building.

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