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Simple models for building-integrated solar thermal systems

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ABSTRACT

Building-integrated solar thermal systems (BIST) outperform building-added solar thermal systems (BAST) due to smaller heat losses at the back of the collector. BIST offer economic advantages, too. The insulation behind the collector can be used to reduce the heating demand of the building as well as to increase the solar thermal yield. Therefore, less material and labour are needed. Of course, the energy flux to the building interior needs to be considered. This energy flux depends in general on the operation of the collector as well as on the irradiance. Several innovative solar thermal building skins have been modelled in detail to analyze this coupling between the active building skin and the building. However, planners need an easy approach to include BIST into their calculations. Often, there is not enough budget to measure and model the new façade. This paper presents several new and simple models which are more accurate than neglecting the coupling to the building and which are less complex than detailed physical models.

1. Introduction

Fig. 1 presents a schematic drawing of a building-added and a building-integrated solar thermal collector. Numerous models of solar thermal collectors have been presented. Some of these models are suitable for building-integrated collectors [1–6]. A general overview of BIST modelling and simulation is provided by [7,8]. With such a detailed model, BIST collectors can be well characterized [9]. However, detailed models need more calculation time than simple models and require some effort to be adjusted to a new collector. The simplest approach is to neglect the building integration and to simulate the collector with an efficiency curve [10] as if it were building-attached and rear-ventilated. This could be called the BAST approach and leads to errors in the calculation of the collector gain and of the energy flux into the building. Analysis of past attempts to find a simple model for a complex BIST façade has shown that the errors at certain time steps can be large and that it is difficult to calculate the heat flux to the building interior correctly [11,12].

The aim of this publication is to present different modelling approaches which can be used as approximations for certain situations and which are located between the very simple and the very detailed approaches. Fig. 2 illustrates the four new approaches schematically. Different methodologies were used to derive these approaches. Approach A is recommended for BIST collectors with good insulation towards the building interior. The efficiency curve is modified to account for reduced back losses. Approach B is recommended if the heat flux from the absorber to the building is important. A conventional collector model is used and the outputs are modified to account for the thermal coupling between the collector and the building. Approach C can be used, for example, if monitoring data of the solar thermal performance is available. The extended efficiency curve increases the calculation accuracy for the solar thermal performance. Approach D is recommended if measurements of the energy flux to the building interior and of the solar thermal performance e.g. on a test facility are available. The necessary data and effort increase from Approach A to Approach D, as does the accuracy of the models.

2. Theory

2.1. Approach A: adaptation of the efficiency curve

If the insulation between the absorber of the BIST collector and the building interior is very thick, the heat losses from the absorber to the interior may be neglected. The best solution would be to measure the efficiency curve of this collector with very good insulation of the back and the edges. If this is not possible due to

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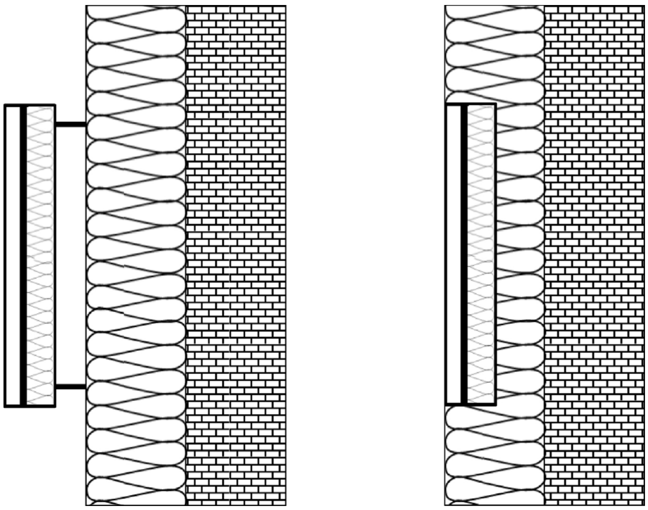

Fig. 1. Schematic drawings of a building-added solar thermal collector (BAST, left-hand side) and a building-integrated solar thermal collector (BIST, right-hand side). The solar thermal absorber is indicated by a thick black line, the masonry with a brick pattern and the insulation of the wall and of the collector with insulation batting patterns.

financial or time restrictions and the efficiency curve is known for the BAST case, the following approach can be used to approximate the efficiency curve without back-surface losses. It is based on modifications of the BAST approach of [10].

First, the effective transmittance–absorptance product $(\tau\alpha)_e$ is calculated from the transmittance of the cover glazing τ and the absorptance of the absorber α [13]:

$$(\tau\alpha)_e \cong 1.01 * \tau * \alpha \quad (1)$$

With this, the collector efficiency factor F' can be calculated using the efficiency for zero temperature difference between the average fluid temperature and the ambient temperature η_0:

$$F'_{BAST} = \frac{\eta_{0,\,BAST}}{(\tau\alpha)_e} \quad (2)$$

$(1 - F'_{BAST})$ equals the fraction of thermal losses of already absorbed energy at zero temperature difference between the average fluid temperature and the ambient temperature.

One important parameter is the fraction of thermal losses from the back surface f_{bl} which are avoided by the building integration compared to all thermal losses of a BAST collector. This fraction can be around 1/7 [13].

The fraction of thermal losses through the back of the collector in the BAST case is equal to $(1 - F'_{BAST})f_{bl}$. The fraction of additional solar thermal gain due to ideal back insulation is equal to $(1 - F'_{BAST})f_{bl}F'_{BIST}$. Without back-surface losses, the collector efficiency factor of the BIST case F'_{BIST} is equal to

$$F'_{BIST} = F'_{BAST} + (1 - F'_{BAST}) * f_{bl}F'_{BIST} \quad (3)$$

and therefore

$$F'_{BIST} = \frac{F'_{BAST}}{1 - f_{bl} + f_{bl}F'_{BIST}} \quad (4)$$

The efficiency at zero temperature difference between the average fluid temperature and the ambient temperature in the BIST case $\eta_{0,\,BIST}$ can be calculated as:

$$\eta_{0,\,BIST} = (\tau\alpha)_e * F'_{BIST} \quad (5)$$

During stagnation, the mass flow and the efficiency are equal to zero. Therefore $\eta_{0,\,BAST}$ is equal to:

$$\eta_{0,\ BAST} = a_{1,\,BAST}\frac{\Delta T_{stag,\,BAST}}{G} + a_{2,\ BAST}\frac{(\Delta T_{stag,\,BAST})^2}{G} \quad (6)$$

The right-hand side of this equation is equal to the thermal losses due to the stagnation temperature. In the BIST case, the fraction f_{bl} of these losses equals the BIST efficiency:

$$\begin{aligned} &\eta_{BIST}(\Delta T_{stag,\,BAST}) \\ &= \eta_{0,\,BIST} - a_{1,\,BIST}\frac{\Delta T_{stag,\,BAST}}{G} - a_{2,\ BIST}\frac{(\Delta T_{stag,\,BAST})^2}{G} \\ &= f_{bl}\eta_{0,\,BAST}. \end{aligned} \quad (7)$$

Assuming that

$$a_{2,\ BIST} = a_{2,\,BAST} \quad (8)$$

$a_{1,\,BIST}$ can be fitted.

In this way, the parameters $\eta_{0,\,BIST}$, $a_{1,\,BIST}$ and $a_{2,\,BIST}$ of the BIST efficiency curve can be calculated from standard BAST parameters. The incidence angle modifier is the same in both cases.

If the thermal coupling between the absorber and the building interior is to be considered, the temperature of the absorber T_{abs} can be approximated by the average fluid temperature T_{fav}. However, a better approximation includes the thermal resistance between the average fluid temperature and the average absorber temperature R_{fa} multiplied by the useful collector gain q_{use}:

$$T_{abs,\,op,\,BIST} = R_{fa}q_{use,\,BIST} + T_{fav} \quad (9)$$

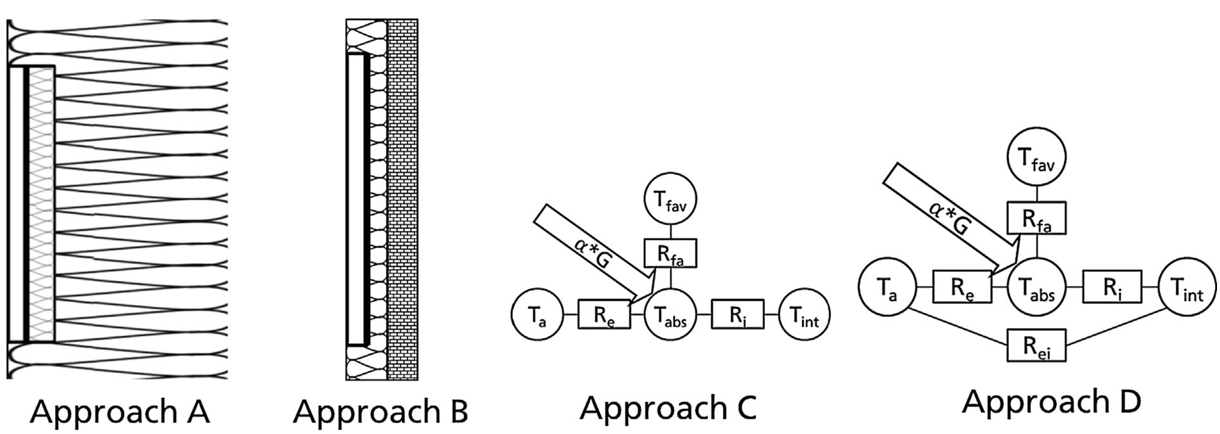

Fig. 2. Schematic drawings illustrating the different approaches for modelling building-integrated solar thermal collectors.