COST Action TU1205 (BISTS)

Building Integration of Solar Thermal Systems

Title:

D 2.5 Report on the new models developed during the project and potential for adaptation for RES

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Contents:

Abstract

The present study has been conducted in the frame of the COST Action TU1205 and it presents an overview on new models developed during the project, with potential for adaptation for RES. Four new and simple models for BIST façade elements are presented. By adopting these models, the thermal coupling of BIST collectors and the building can be taken into account. Different approaches are proposed, depending on several parameters related with the specific case that is going to be studied. Finally, issues about the *g* value for the case of transparent façade collectors are presented and critically discussed. Conclusively, by considering the importance of BIST modelling, the present work provides useful information for the development of BIST models, based on different approaches.

1. Introduction

Architectural integration is an important issue in the field of solar systems, including the case of building-integrated solar thermal (BIST). BI solar systems present multiple advantages since they replace a building component (façade, roof, etc.). For example, building-integrated solar systems show higher aesthetic value than the traditional building-added solar thermal (BAST) configurations. In the literature there are experimental as well as modelling studies about BIST. Certainly, the experimental works are important in order to test the behaviour of a system; nevertheless, modelling can be adopted to predict system performance (saving time and costs). Thereby, further modelling studies are needed (along with experimental works) for BIST systems (Lamnatou et al., 2015a).

A literature review reveals that there are BIST modelling studies with emphasis on the system itself (Lamnatou et al., 2015a) and with emphasis on the coupled building/system configuration (Lamnatou et al., 2015b). In terms of the types of simulations, these include for example energetic, thermal, energetic/thermal and optical simulations (Lamnatou et al., 2015a, 2015b).

In Fig. 1 schematics of a building-added and a BIST collector are illustrated (Maurer et al., 2015a). By examining the BIST models in terms of their simplicity or complexity, it can be noted that detailed models need more calculation time than simple models and they also require an effort in order to be adjusted to a new collector. The simplest approach is to neglect the issue of building integration and to simulate the collector as if it were building-attached and rear-ventilated. This approach could be called BAST approach and it should be highlighted that it leads to errors in terms of the calculation of the collector gain and of the energy flux into the building (Maurer et al., 2015a).

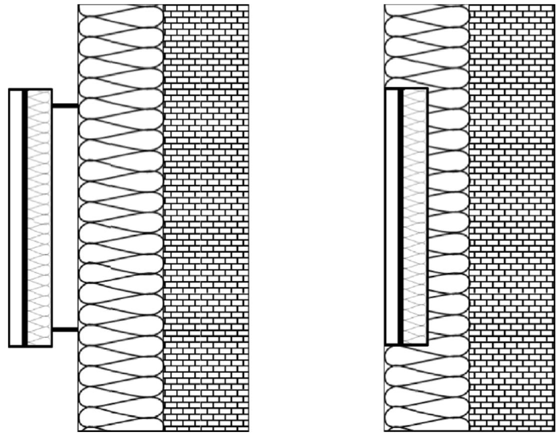

Figure 1. Schematics of a BAST collector (left-hand side) and of a BIST collector (right-hand side). In the schematics, the solar thermal absorber is indicated by a thick black line, the masonry with a brick pattern and the insulation of the wall and of the collector with insulation batting patterns (Source: Maurer et al., 2015a).

In the frame of the above mentioned concepts, Maurer et al. (2015a) presented different modelling approaches which can be adopted as approximations for certain cases and which are classified between very simple and very detailed approaches. Based on these issues, Fig. 2 shows (schematically) the four new approaches. Different methodologies were utilized in order to derive these approaches (Maurer et al., 2015a):

- Approach A is appropriate for BIST collectors with good insulation towards building interior. The efficiency curve is modified in order to account for reduced back losses.

- On the other hand, approach B is suitable if the heat flux from the absorber to the building is important. A conventional collector model is adopted and the outputs are modified in order to account for the thermal coupling between the collector and the building.

- In addition, approach C can be used, for example, if monitoring data of the solar thermal performance are available. Moreover, the extended efficiency curve increases the calculation accuracy for the solar thermal performance.

- Furthermore, approach D is suitable if measurements of the energy flux to the building interior and of the solar thermal performance e.g. on a test facility are available.

Maurer et al. (2015b) noted that the data needed and the effort increase from Approach A to Approach D, as it does the accuracy of the models.

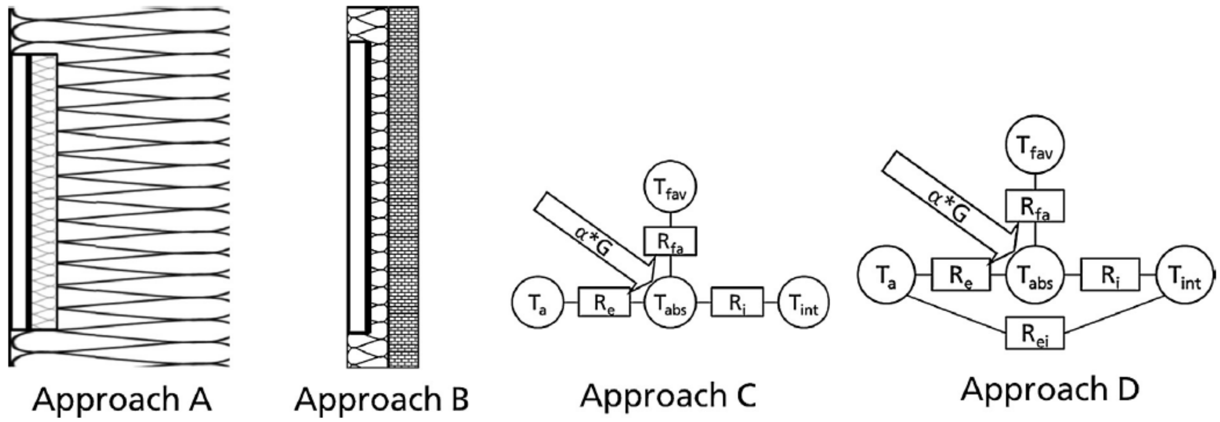

Figure 2. Schematics showing the different approaches for modelling of BIST collectors (Source: Maurer et al., 2015a).

2. The theory related with the proposed approaches

2.1. Approach A: Adaptation of the efficiency curve

For the case of very thick insulation between the absorber of the BIST collector and the building interior, the heat losses from the absorber to the interior may be neglected (Maurer et al., 2015a). For this case, the best solution would be to measure the efficiency curve of this collector with very good insulation of the back and the edges. However, if this is not possible because of financial or time restrictions and the efficiency curve is known for the BAST, the following approach can be adopted in order to approximate the efficiency curve without back-surface losses. This option it is based on modifications of the BAST approach presented by Cooper and Dunkle (1981). At this point it should be noted that Cooper and Dunkle (1981) conducted a study about the analysis of a non-linear flat-plate collector in which the overall loss coefficient is assumed to be a linear function of the temperature difference between the fluid in the collector and the environment. The instantaneous performance of collectors calculated by adopting linear and non-linear models has been presented in terms of three dimensionless numbers. Cooper and Dunkle (1981) mentioned that for a parabolic solar radiation profile, the average daily performance for a constant fluid inlet temperature can be presented in terms of three further dimensionless numbers. A method of calculating linear collector performance characteristics from non-linear curve fitting to experimental results was presented so that the predicted daily performance from non-linear and linear curve fits can be compared. Finally, Cooper and Dunkle (1981) highlighted that in most circumstances, a linear fit is adequate.

According to approach A (Maurer et al., 2015a), firstly 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 (details can be found in Duffie and Beckman (2006)):

$$(\tau\alpha)_e \cong 1.01 * \tau * \alpha \qquad \text{Eq. (1)}$$

Based on the above mentioned factors, the collector efficiency factor F' can be calculated by utilizing the efficiency for zero temperature difference between the average fluid temperature and the ambient temperature η_0:

$$F'_{\mathrm{BAST}} = \frac{\eta_{0,\,\mathrm{BAST}}}{(\tau\alpha)_{\mathrm{e}}} \qquad \text{Eq. (2)}$$

Related with the above presented issues, it should be noted that $(1-F'_{BAST})$ equals the fraction of thermal losses of already absorbed energy at zero temperature difference between the average fluid temperature and the ambient temperature.

It should be also highlighted that one important factor is the fraction of thermal losses from the back surface f_{bl} which are avoided by the building integration compared to all the thermal losses of a BAST collector. This fraction can be around 1/7 (details about this issues can be found in Duffie and Beckman (2006)).

Moreover, the fraction of the thermal losses through the back of the collector for the case of BAST is equal to $(1-F'_{BAST})f_{bl}$. The fraction of the additional solar thermal gain because of the 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:

$$F'_{\mathrm{BIST}} = F'_{\mathrm{BAST}} + (1 - F'_{\mathrm{BAST}}) * f_{\mathrm{bl}} F'_{\mathrm{BIST}} \qquad \text{Eq. (3)}$$

and thereby,

$$F'_{\mathrm{BIST}} = \frac{F'_{\mathrm{BAST}}}{1 - f_{\mathrm{bl}} + f_{\mathrm{bl}} F'_{\mathrm{BIST}}} \qquad \text{Eq. (4)}$$

Furthermore, 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 based on the following equation:

$$\eta_{0,\,\mathrm{BIST}} = (\tau\alpha)_{\mathrm{e}} * F'_{\mathrm{BIST}} \qquad \text{Eq. (5)}$$

In addition, during stagnation, the mass flow and the efficiency are equal to zero. Thereby, $\eta_{0,BAST}$ is equal to:

$$\eta_{0,\,\mathrm{BAST}} = a_{1,\,\mathrm{BAST}} \frac{\Delta T_{\mathrm{stag,\,BAST}}}{G} + a_{2,\,\mathrm{BAST}} \frac{(\Delta T_{\mathrm{stag,\,BAST}})^2}{G} \qquad \text{Eq. (6)}$$

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

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

By assuming that

$$a_{2,\,\mathrm{BIST}} = a_{2,\,\mathrm{BAST}} \qquad \text{Eq. (8)}$$

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

Based on the above mentioned, the parameters $\eta_{0,\mathrm{BIST}}$, $a_{1,\mathrm{BIST}}$ and $a_{2,\mathrm{BIST}}$ of the BIST efficiency curve can be evaluated from standard BAST parameters. In terms of the incidence angle modifier, it is the same for both cases.

For the case of considering the thermal coupling between absorber and building interior, the temperature of the absorber T_{abs} can be approximated by the average fluid temperature T_{fav}. Nevertheless, 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}.

$$T_{\mathrm{abs,\,op,\,BIST}} = R_{\mathrm{fa}}\,q_{\mathrm{use,\,BIST}} + T_{\mathrm{fav}} \qquad \text{Eq. (9)}$$

On the other hand, within the building model, the façade collector area can be considered to be adiabatic. In addition, a more accurate approach is linking the absorber temperature with the building model in order to include the corresponding heat flux in the building simulation, which was neglected for the calculation of the collector efficiency. It should be noted that within the TRNSYS simulation environment (Beckman et al., 1994), a simple connection can be achieved by estimating the thermal resistance $R_{\mathrm{i,BIST}}$ between the absorber and the building interior and calculating the heat transfer into the building q_{int} with the temperatures of the absorber T_{abs} and the interior T_{int}.

It should be also highlighted that if an extremely well insulated wall is utilized within the building type, then q_{int} can be inserted directly as an additional wall gain. More advanced methods of coupling have been presented by Maurer and Kuhn (2012) and Hauer et al. (2012). Details about the work of Maurer and Kuhn (2012) are presented in subsection 4 of the present report.

More details about the adopted equations, based on Approach A, can be found in the studies of Maurer et al. (2015a, 2015b).

2.2. Approach B: Adaptation of the collector results

First of all it should be clarified that even if the heat flux between the BIST absorber and the building interior cannot be neglected, the collector may still be simulated as if it were building-attached, by adopting certain corrections in order to approximate the true heat flux to the interior and the increased collector gain (Maurer et al., 2015a).

As a first step, the thermal resistance between the absorber and the interior $R_{\mathrm{i,BIST}}$ for the BIST case should to be calculated and also the thermal resistance $R_{\mathrm{i,BAST}}$ between the absorber and the air behind the back of the collector for the case of BAST.

For each time step of the simulation, the back losses of the collector can be evaluated for the BAST and for the BIST case based on the following equations:

$$q_{\mathrm{int,\,BAST}} = \frac{1}{R_{\mathrm{i,\,BAST}}}(T_{\mathrm{abs,\,BAST}} - T_{\mathrm{a}}) \qquad \text{Eq. (10)}$$

$$q_{\mathrm{int,\,BIST}} = \frac{1}{R_{\mathrm{i,\,BIST}}}(T_{\mathrm{abs,\,BIST}} - T_{\mathrm{int}}) \qquad \text{Eq. (11)}$$

with the ambient air temperature T_{a} and the temperature of the building interior T_{int}.

More details about the adopted equations, according to Approach B, can be found in the studies of Maurer et al. (2015a, 2015b).

2.3. Approach C: Extended efficiency curve

An extended efficiency curve including the temperature of the building interior was proposed by Pflug et al. (2013). For this case, the efficiency η depends on the temperature of the ambient and of the building interior:

$$\eta = \eta_0 - a_{1,\,\mathrm{ext}} * x - a_{2,\,\mathrm{ext}} * x^2 * G - a_{1,\,\mathrm{int}} * y - a_{2,\,\mathrm{int}} * y^2 * G \qquad \text{Eq. (12)}$$

with

$x = (T_{\mathrm{fav}} - T_{\mathrm{a}})/G$ [m^2 K/W]

$y = (T_{\mathrm{fav}} - T_{\mathrm{int}})/G$ [m^2 K/W]

$a_{1,\,\mathrm{int}}$: internal linear heat loss coefficient [W K^{-1} m^{-2}]

$a_{2,\,\mathrm{int}}$: internal second-order heat loss coefficient [W K^{-2} m^{-2}]

$a_{1,\,\mathrm{ext}}$: external linear heat loss coefficient [W K^{-1} m^{-2}]

$a_{2,\,\mathrm{ext}}$: external second-order heat loss coefficient [W K^{-2} m^{-2}]

G: total irradiance on the collector surface [W/m^2]

$T_{\mathrm{fav}} = (a_{1,\,\mathrm{int}} + T_{\mathrm{fo}})/2$: the mean fluid temperature in the collector

T_{int}: the temperature of the building interior

T_{a}: the ambient temperature

η_0: the efficiency at zero temperature difference between the fluid, the front and the back of the collector.

More details about the proposed equations based on Approach C can be found in Maurer et al. (2015a, 2015b).

In terms of the study of Pflug et al. (2013), a new simplified model in order to calculate the efficiency of Transparent Solar Thermal Collectors (TSTCs) was presented and it was compared with other models. A detailed, validated model of a TSTC was adopted in order to parameterize the simplified model by utilizing different simulation data sets. The first investigations revealed that the formula was not able to predict the heat flux Q_{int} from the collector to the interior. Nevertheless, the formula was proven to accurately model the collector efficiency η for several sets of simulations. In addition, the influence of the choice of the data set utilized to parameterize the simulations appeared to be negligible. Pflug et al. (2013) noted that this new simplified model is able to model the collector gain and further tests by adopting other types of solar thermal façade collectors need to be conducted. Moreover, the parameters can be fitted on the basis of measurement or on the basis of a physical model. It was also mentioned that there is a need to find a simplified model which is able to predict the heat flux Q_{int} to the interior and a long-term goal is to have a comparison tool for façade collectors (Pflug et al., 2013).

Pflug et al. (2013) mentioned that the TSTC model developed in the frame of the work of Maurer (2012) has many input and outputs. The two most significant outputs are the heat flow from the component towards the interior and the heat flow removed by the fluid. In this way, Pflug et al. (2013) highlighted the need for a simplified model. A simplified model of TSTC was already presented (Maurer et al., 2012). Nevertheless, this simplified model was not offering an accurately modeling in terms of Q_{int} and Q_{use}, since it did not take into account the effect of the operating mode on Q_{int} and underestimated Q_{use} with increasing the fraction of the diffuse irradiance. In this way, the calculated heating and cooling loads were sometimes over or underestimated. On the other hand, the detailed model is accurate but it is complex, with more than 300 parameters to fit on the basis of measurements. Pflug et al. (2013) noted that except of the simplicity in terms of the use, a simplified model provides additional benefits:

-A simplified model with only 5 parameters to fit needs only a limited number of expensive calorimetric measurements.

- Reduction of the computational time can be achieved by adopting a simplified model instead of a detailed one.

- A simplified model may allow comparisons of façade collectors by including the simplified model in a norm, as for the case of standard roof collectors (Norm EN 12975-2:2006).

In this way, Pflug et al. (2013) noted that their study aims to propose a new simplified model, in order to offer a good modeling of Q_{use} and Q_{int}. In the conclusions of the study of Pflug et al. (2013) it was noted that:

- A new simplified model in order to calculate the efficiency of TSTCs was presented and it was compared with other models and a detailed, validated model of a TSTC was adopted to parameterize the simplified model by utilizing different simulation data sets.

- The first investigations revealed that the formula was not able to predict the heat flux Q_{int} from the collector to the interior but the formula was proven to accurately model the collector efficiency η for several sets of simulations. The effect of the choice of data set used in order to parameterize the simulations was negligible.

- This new simplified model is able to model the collector gain but more tests with other types of solar thermal façade collectors need to be conducted. On the other hand, the parameters can be fitted on the basis of measurements or on the basis of a physical model. Furthermore, it is still necessary to find a simplified model which offers prediction of the heat flux Q_{int} to the interior. A long-term goal is to obtain a comparison tool for façade collectors for opaque configurations (Pflug et al., 2013).

2.4. Approach D: Simple node model

In the frame of this approach, as an example of simple node models, the model illustrated in Fig. 3 was studied. The parallel resistance R_{ei} of this model can account for the heat flux around the collector edges.

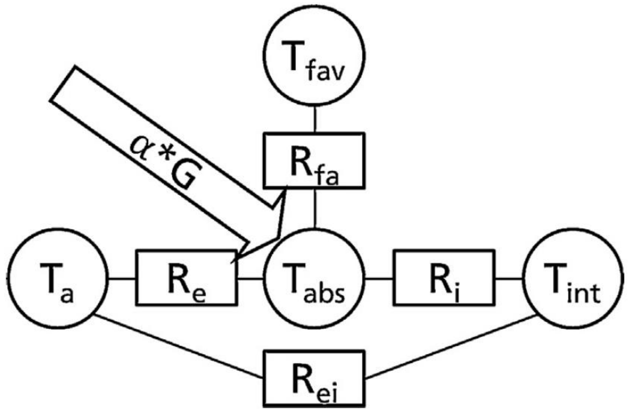

Figure 3. Schematic of the simple node model. It should be noted that there is a parallel thermal resistance R_{ei} between the temperatures of the ambient air T_a and the building interior T_{int}. Moreover, the absorber temperature T_{abs} is connected to T_a by the thermal resistance R_e and to T_{int} by the thermal resistance R_i. In addition, the absorber receives the absorbed radiation αG and it is connected by the thermal resistance R_{fa} to the average fluid temperature T_{fav} (Source: Maurer et al., 2015a).

In order to assess this approach, the detailed physical model of Maurer et al. (2013) was adopted in order to calculate 2520 different cases. The following values were combined with each other:

- Ambient temperatures of −20, 0, 20 and 40°C

- Indoor temperatures of 0, 10, 20, 30 and 40°C

- Fluid mass flow rates of 0 and 0.02 kg/(m^2 s)

- Fluid inlet temperatures of 5, 15, 25, 35, 45, 55, 65, 75 and 85°C

- Irradiance values of 0, 200, 400, 600, 800, 1000 and 1200 W/m^2

The scenarios cover most of the cases of the climate of Central Europe (but are not representative in their distribution).

The thermal resistances R_e, R_i, R_{ei}, R_{fa} and the absorptance α were then varied in order to minimize the differences between the detailed physical model and the simple node model.

3. Results based on the proposed approaches and discussion

For the case where no simple model is utilized and the coupling between the absorber and the building interior is neglected, the heat flux from the building interior to the BIST element is overestimated for winter and the heat flux from the BIST element to the building interior is underestimated for summer. Furthermore, the collector gain is underestimated throughout the whole year.

3.1. Approach A: Adaptation of the efficiency curve

In Fig. 4, the efficiency curves for a BAST collector with the derived efficiency curves for the BIST case (f_{bl} = 1/7) as well as for a BIST_0.9bl case with the fraction of back losses reduced by 10% are illustrated (Maurer et al., 2015a). It should be noted that the relative error between BIST calculation and a simulation without coupling (BAST) increases by increasing the temperature difference between the fluid T_{fav} and the ambient T_a and by decreasing the irradiance G. On the other hand, at BIST stagnation temperature, the absolute error of the efficiency is 0.12 which equals 120 W/m^2 for an irradiance of 1000 W/m^2.

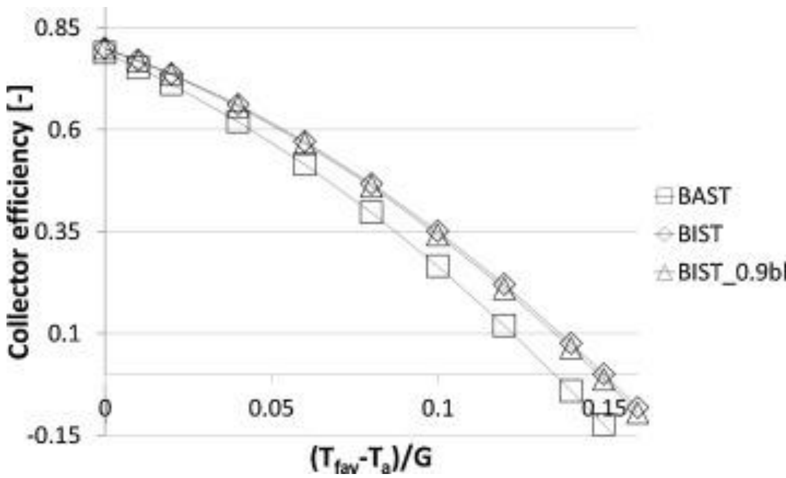

Figure 4. The efficiency of the collectors vs. the temperature difference between the fluid T_{fav} and the ambient T_a and the irradiance G, for the BAST case, the BIST case and the BIST_0.9bl case with a smaller fraction of the back losses (Source: Maurer et al., 2015a).

The authors of the above mentioned study, Maurer et al. (2015a), noted that the accuracy could be further improved by adopting a weighted average between the temperatures of the ambient and of the interior in order to calculate the collector gain. Nevertheless, the collector losses are not linear which means a complexity similar to the nodal model presented in the frame of Approach D.

3.2. Approach B: Adaptation of the collector results

For the case of Approach B, the temperature of the building interior is included for the calculation of the collector gain and thereby, also for the calculation of the absorber temperature.

If it is assumed that the U value is 0.24 W/(m^2 K), the ambient temperature is 30 °C, the temperature of the building interior is 25°C, the irradiance is 1000 W/m^2 on the façade and the back losses are 1/7, the absorber reaches a stagnation temperature of 165°C for the BAST case. On the other hand, for the BIST case, the stagnation temperature is 180°C according to the parameters from Approach A (Maurer et al., 2015a).

3.3. Approach C: Extended efficiency curve

Maurer et al. (2015a) highlighted that the accuracy of Approach C depends on the accuracy of the parameters η_0, $a_{1,\text{ext}}$, $a_{2,\text{ext}}$, $a_{1,\text{int}}$ and $a_{2,\text{int}}$ and the thermal resistance between the absorber and the interior $R_{\text{i,BIST}}$. As it has been presented in the work of Pflug et al. (2013), the extended efficiency curve has a root-mean-square error (RMSE) of 0.0023 for the efficiency compared to 0.0112 for the standard efficiency curve which means that the benefit of the extended efficiency curve is limited. Nevertheless, if, for example, monitoring data are available to fit the efficiency curve, the extended efficiency curve should be used since it offers higher accuracy with a little extra effort.

3.4. Approach D: Simple node model

A comparison between the simple node model of Approach D and the detailed physical model resulted in a root mean square error (RMSE) of 2 W/m^2 for the heat flux to the building interior and of 13 W/m^2 for the collector gain (Maurer et al., 2015a). For an average absolute value of 28 W/m^2 for the heat flux to the interior and for a value of 152 W/m^2 for the collector gain when the collector is operating, the uncertainty of the heat flux to the interior and of the collector gain can be estimated to be 8%.

3.5. Comparison of the approaches

Maurer et al. (2015a) noted that from Approach A to Approach D, the required quality of the necessary inputs increases. It was also mentioned that approach A only needs the efficiency parameters of the collector datasheet and it is appropriate when there is good insulation between the absorber and the building interior. On the other hand, when the heat flux between the absorber and the interior is relevant, Approach B is recommended. In addition, for new BIST elements, simultaneous measurements of the collector gain and the heat flux to the interior are recommended in order to calibrate the simple model of Approach D. Maurer et al. (2015a) also mentioned that this already offers an analysis of the advantages of the new component for various conditions. For the cases where high accuracy is needed, the model of Approach D can be easily extended in order to include additional relevant physical effects. For the cases where the absorber temperature is set to the ambient temperature during night (conditions of no irradiance and no fluid flow) the heat loss of the building does not include the thermal resistance between ambient and absorber. For the cases where the building is well insulated, this may have negligible effect. On the other hand, for less well-insulated buildings or for higher accuracy, the U value of the BIST building envelope can be adopted instead of R_i in this case.

4. The role of *g* value for transparent façade collectors

Given the fact that transparent façade collectors present an increasing interest (Lamnatou et al., 2015a, 2015b), showing advantages such as visual transparency and solar control (Maurer and Kuhn, 2012), subsection 4 highlights some important issues related with the role of the *g* value for the case of transparent façade collectors.

In the frame of this goal, a collector model with an advanced calculation of the transmission of diffuse radiation and a connection to the building which offers analysis of the collector gains and of the *g* value (that is also known as “solar factor”, “solar heat gain coefficient (SHGC)” or “total solar energy transmittance”) is presented. It should be noted that the model is implemented as a TRNSYS Type and a coupled simulation between a collector and a room is evaluated for different façade constructions (Maurer and Kuhn, 2012).

4.1. General issues related to the proposed model

Fig. 5 illustrates an overview of the main components of the simulation model (Maurer and Kuhn, 2012). A thermal simulation model and a connection of the new collector Type 871 to the building Type in the TRNSYS simulation environment (Klein et al., 2004), are included. The same connection strategy is also adopted by the new BlackBoxType 861 for façades with solar control systems.

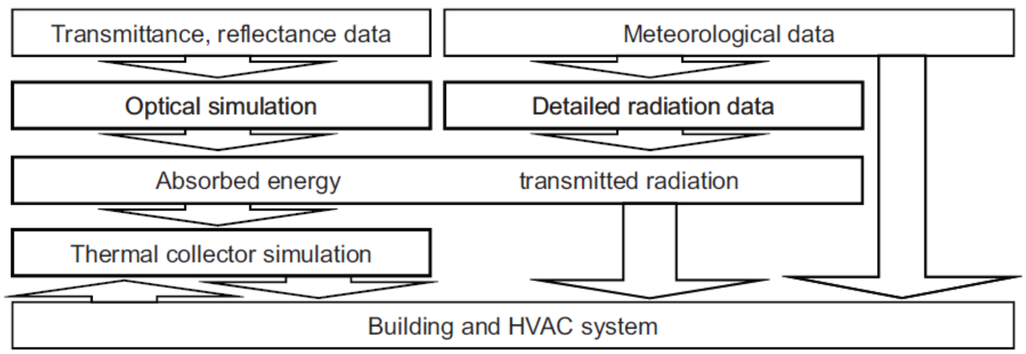

Figure 5. Presentation of the simulation components of Type 871 (Source: Maurer and Kuhn, 2012).

4.2. Optical simulation

For the optical simulation (Maurer and Kuhn, 2012), angle-dependent, polarization dependent spectral transmittance and reflectance data are necessary separately for direct and diffuse radiation for each layer of the transparent solar thermal collector.

The finding of the optical simulation is the effective absorptance for each collector layer (one result per polarization state). Another finding is the effective transmittance of the entire collector for each polarization state. By assuming that the solar irradiation incident on the collector is unpolarized, the total absorptance of each layer and the solar transmittance is the average of the respective values for each polarization state (Maurer and Kuhn, 2012).

4.3. Detailed radiation data and the role of the absorbed energy

Maurer and Kuhn (2012) noted that the direct radiation given by typical meteorological data sets can be adopted directly as input for the proposed model. Nevertheless, in order to model the behaviour of the diffuse radiation correctly, the sky is first divided into 145 sky patches according to Tregenza (Tregenza, 1987; Kuhn et al., 2001; Reinhart and Walkenhorst, 2001). In addition, it was noted that the radiance of each sky patch is evaluated based on Perez model (Perez et al., 1993). Moreover, the ground is divided into 90 patches and their radiance is calculated with respect to the ground reflectance (albedo).

4.4. Thermal simulation

In Fig. 6 a schematic of the thermal simulation is illustrated. The current implementation offers twelve layers, each of which can be activated in order to represent a component layer (Maurer and Kuhn, 2012).

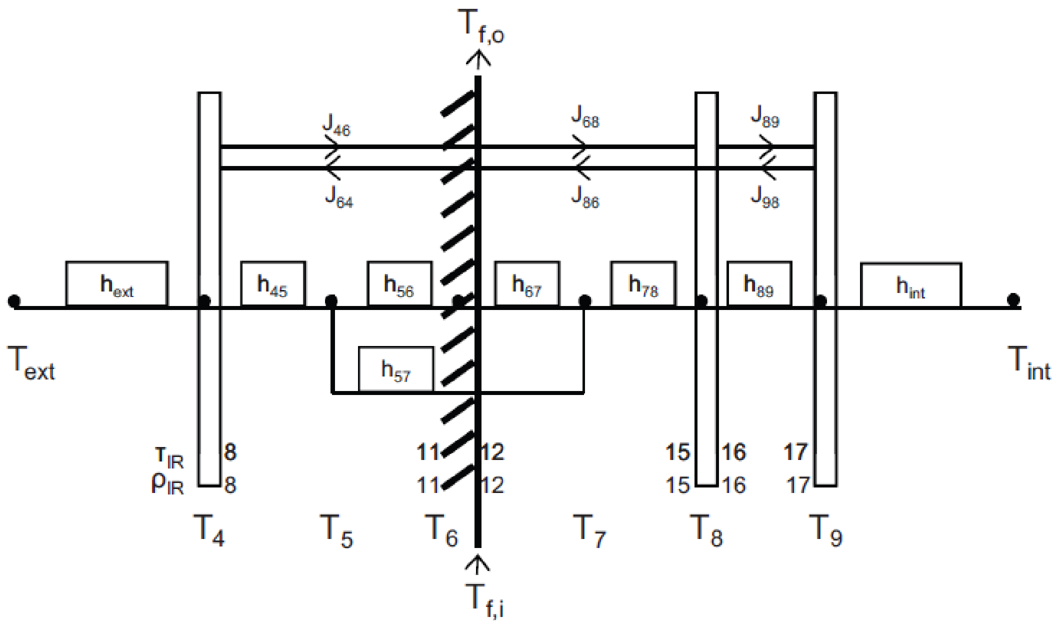

Figure 6. Overview of a single thermal simulation of Type 871. Definitions: Between the ambient temperature T_{ext} and the indoor temperature T_{int} there are five temperature nodes T_x. T_4 represents the temperature of the cover glass, T_6 is the absorber temperature, T_5 and T_7 are the average gas temperatures and T_8 and T_9 represent the glass temperatures. The convective heat transfer coefficients h_{xy} and the infrared radiations J_{xy} connect these nodes. For the J_{xy} calculations, the infrared transmittance and reflectance of each layer is needed. Temperature node T_6 is also connected to the mean fluid temperature $T_{f,av} = (T_{f,i} + T_{f,o})/2$ (Source: Maurer and Kuhn, 2012).

4.5. Connection to the building

In the study of Maurer and Kuhn (2012) it was noted that the connection between the collector and the building model should meet certain requirements: to guarantee the correct transmission of the solar radiation into the building and out of the building and the correct heat flux into or out of the building. For the case of implementing the collector model as the new Type 871 in TRNSYS, Maurer and Kuhn (2012) proposed to connect it to the multi-zone building Type 56 via a modified window.

4.6. General comments and concluding remarks

A new Type 871 was developed by Maurer and Kuhn (2012) which is able of modelling transparent solar thermal collectors (in a very detailed way) while opening the door to coupled system simulations with a building and an HVAC system.

Maurer and Kuhn (2012) noted that the new BlackBoxType 861 proposes the detailed façade model presented by Kuhn et al. (2011) into TRNSYS and improves the calculation of the diffuse transmission in order to model complex passive façades more accurately. The validation of the models was conducted successful and the simulations showed remarkable savings of the primary energy (around 30%) while the visual transparency simultaneously increased.

Moreover, Maurer and Kuhn (2012) mentioned that a comparison between coupled system simulations and monitoring findings could minimize the uncertainty of the predicted primary energy demand. Simulations for the case of active façades require detailed modelling since a constant *g* value cannot reflect their characteristics. The solar gains for the case of active façade components depend on irradiation and collector operation mode, and show considerable variations. Nevertheless, a detailed model such as Type 871 offers an accurate prediction of collector gain, heating and cooling load and even for the indoor surface temperatures in order to permit detailed calculations of the thermal comfort. The BlackBoxType 861 shows unprecedented accuracy in terms of modelling glazing with blinds in TRNSYS (Maurer and Kuhn, 2012).

5. Conclusions

The present report presents an overview on new models developed during the project and which show the potential for adaptation for RES.

In the frame of this scope, four new and simple models for BIST façade elements are presented. By using these models, the thermal coupling of BIST collectors and the building can be taken into account. Different approaches are proposed. Approach A is recommended for buildings with good insulation between the absorber and the building interior. Approach B is suitable for cases when the heat flux between the absorber and the building interior cannot be neglected. For the case when monitoring data of the BIST solar thermal performance are available, Approach C can be useful with its improved formula for the collector efficiency. On the other hand, if measurements of the energy flux to the interior and of the solar thermal performance, for example, on a BIST test facility are available, the model of Approach D can be calibrated and it well characterizes the BIST building envelope.

Finally, issues about the *g* value for the case of transparent façade collectors are presented and critically discussed.

Conclusively, by taking into account the importance of modelling in the field of BIST systems, the present report provides useful information for the development of BIST models, based on different approaches.

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