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MODELLING OF ACTIVE BUILDING ENVELOPES FOR COST-EFFECTIVE EVALUATION

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Abstract

Active building envelopes have provided cost reductions of 40% compared to a separate installation of solar collectors on a building envelope. However, solar building envelopes are more complex than conventional building envelopes due to their additional solar function. This paper first explains this complexity before describing methods to handle this complexity. The focus of the simulation models is good accuracy at low costs. From the development of innovative solar envelopes up to the general planning and construction of solar architecture, this paper provides seven recommendations to optimize the cost-benefit ratio of simulations of active building envelopes.

Keywords

solar building envelopes, building-integrated solar thermal (BIST), building-integrated photovoltaics (BIPV), building-integrated solar systems (BISS), solar architecture

1. Introduction

Multifunctional building envelopes including solar energy converters aim for a competitive cost-benefit ratio by providing the additional solar energy function at little extra cost compared to conventional building envelopes. For building-integrated solar thermal (BIST) systems, it has been shown that 40% of the investment costs have been saved in two analysed BIST building projects (Maurer, Cappel, & Kuhn, submitted). This means that the additional investment cost of building a solar thermal building envelope instead of building a conventional building envelope plus a conventional solar thermal collector can be 40% cheaper per square metre collector. Therefore e.g. IEA SHC Task 56 is currently investigating solar building envelopes. One challenge for solar building envelopes is that their additional function makes them more complex than conventional building envelopes. This paper first analysis these challenges before discussing possible solutions and contributions for even more cost-effective solar building envelopes. This conference paper is based on (Maurer & Kuhn, submitted).

2. Theory

Compared to conventional solar thermal collectors, BIST is more complex because not only the ambient temperature influences the solar thermal performance, but also the temperature of the building interior. Figure 1 illustrates this situation, which influences the solar thermal performance. Additionally, the energy flux to the building interior needs to be quantified, which goes beyond the conventional measurements of solar thermal collectors e.g. according to (ISO 9806).

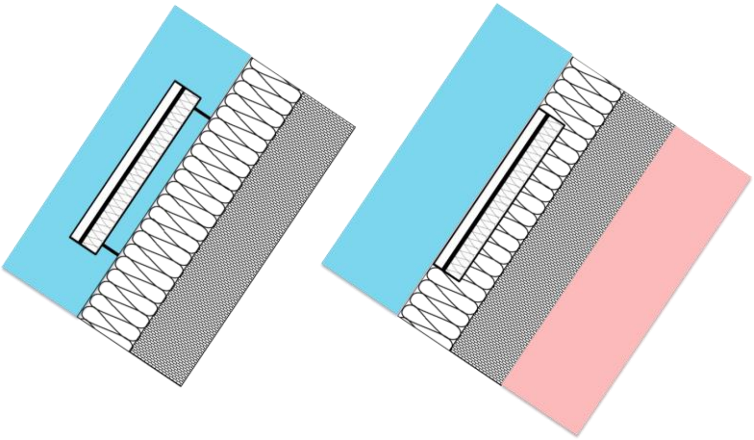


Figure 1. Schematic drawings of a building-added solar thermal collector (left) and building-integrated solar thermal collector (right)

Compared to conventional elements of the building envelope, BIST is more complex because the heat flux through the building envelope without irradiance does not depend only on the temperature difference, but also on the operating mode of the collector. This means that a constant U value does not characterize solar thermal envelopes correctly. The energy flux to the building interior with solar irradiance on the collector also depends on the operating mode of the collector. This means that a constant g value (also known as solar heat gain coefficient SHGC or solar factor or total solar energy transmittance) does not characterize solar thermal envelopes correctly (Maurer & Kuhn, 2012).

Typically, an active solar envelope will not be operated without irradiance. So a constant U value with a variable g value may work for a number of cases. However in general, active solar envelopes can supply energy to the envelope and therefore influence the U and g values; this applies not only to BIST, but also to building-integrated photovoltaics (BIPV).

To handle this complexity, detailed physical models of active solar envelopes can be generated (Lamnatou, Mondol, Chemisana, & Maurer, 2015b, 2015a; Maurer, 2012). They typically consist of an optical simulation which handles the multiple reflections and a thermal simulation with thermal nodes and energy fluxes between these nodes. One challenge can be integration of the detailed collector simulation model into an existing building simulation, especially if the source code of the building model is not accessible.

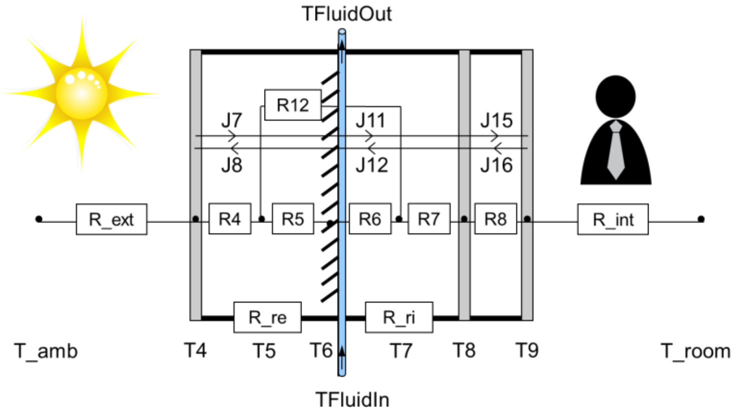
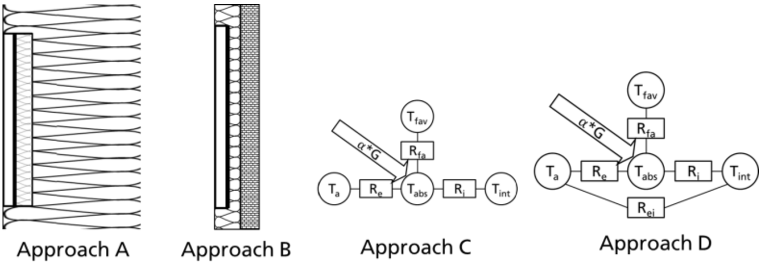


Figure 2. Schematic drawing of a detailed physical model of a semi-transparent solar thermal facade collector (Maurer, 2012)

Simple BIST models were investigated (Maurer et al., 2013; Pflug, Di Lauro, Kuhn, & Maurer, 2013) and newly developed (Maurer, Cappel, & Kuhn, 2015). Figure 3 schematically illustrates all four simple approaches. Approaches A and B of (Maurer, Cappel et al., 2015) are recommended for cases where conventional solar thermal collectors are integrated into the building envelope and where the conventional solar thermal performance parameters according to (Cooper & Dunkle, 1980; ISO 9806) are available. Approach A modifies these parameters for cases with good thermal insulation in order to adapt them to the building integration. Approach B uses the original parameters for cases with poor insulation, but corrects the results to account for the building integration. While Approach C is suited for special cases where detailed measurement data is available, Approach D proposes a very simple node model which reaches a relatively good agreement with the results of a detailed model.



Approach A Approach B Approach C Approach D

Figure 3. Schematic illustration of the four simple approaches to model BIST

The modelling approaches mentioned above can be extended for the description of building-integrated photovoltaic-thermal (BIPVT) elements. Simple approaches for including the photovoltaic function consider only temperature-dependent PV efficiency, whereas detailed approaches include the modelling of the effects of partial shading (Maurer, Sprenger, Lämmle, & Kuhn, 2015). The methods for the modelling of BIPVT, described by (Maurer, Sprenger et al., 2015), can also be used for BIPV elements without solar thermal functionality.

3. Results and Discussion

The simulation of active solar envelopes should provide the necessary accuracy at lowest possible costs. The first step is therefore to analyse which accuracy is needed in order to choose the most cost-effective modelling approach.

Semi-empirical models are often the best choice for the evaluation of custom-built collectors or concepts for new multifunctional building envelope elements which actively convert solar energy. Semi-empirical models combine parametrized physical calculation models and specific measurements to determine unknown “fit parameters” or “model parameters”. The experimental determination of the model parameters ensures that non-ideal properties of the building envelope elements are taken into account in the evaluation. The combination of parametrized physical calculation models and measurements for the calibration of the model therefore offers the best ratio of costs to benefits in most cases.

For innovative products of active solar building envelopes, calorimetric measurements are often crucial for the validation and calibration of simulation models. To date, there is no standard which defines the criteria for a validated simulation model of a solar building component. Such a standard could increase confidence in simulation models which had been validated and calibrated according to the standard and could also decrease the costs.

The mathematical complexity of simulation models for multifunctional building envelope elements is irrelevant as long as the models are easy to use. An important next step is therefore a user-friendly front end, integrated into a powerful whole-building energy-simulation environment. The feasibility of a “plug and play interface” has been shown for the case of semi-transparent solar thermal façade collectors (Maurer et al., 2013). Here, the semi-transparent solar thermal façade collector was represented by a TRNSYS Type with a similar user interface to other solar thermal collectors or walls. The new TRNSYS Type was used by HVAC planners to perform a complex simulation of the whole building energy demand including the detailed modelling of the control of the technical building systems.

However, different stakeholders of the building process use different simulation environments due to very specific advantages. To address this issue, it is recommended to provide the same simulation model of a solar building component in all necessary (or at least in the most important) simulation environments.

At different times within the building process, the multifunctional building envelope components are specified with different levels of detail and simulations with different accuracy levels are needed. One approach is to combine for example a model with few inputs and low accuracy and a model with many inputs and high accuracy within one adaptive multi-environment simulation model which can switch its accuracy depending on the available input data at this stage of the building process.

Building information modelling (BIM) aims to improve the exchange of data within the building process. To date, the industrial foundation classes (IFC) define a structure of text data which can be exchanged within this format. It is therefore recommended by (Maurer, Sprenger et al., submitted) to include functions in machine code in this data exchange. This could lead to greater accuracy and lower costs for the planning, construction and facility management of buildings due to the increased exchange of know-how.

4. Conclusions

Active building envelopes offer exciting advantages such as significant cost reduction when compared to the installation of building-added solar elements. However, they are more complex than conventional building envelopes and additional, conventional solar elements. This paper first explains this complexity before describing methods to handle this complexity:

1. If a simple model is accurate enough, no detailed model needs to be developed.
2. If some parameters cannot be calculated accurately enough, measurements should be performed to derive them.
3. It is recommended that a standard for the validation of simulation models of building envelopes be developed to ensure the quality of the models.
4. A model can be complex internally as long as it is easy to use for the planners.
5. The model of an innovative building envelope should be available in all relevant simulation environments.
6. Adaptive models are recommended which can provide a first estimate with little input data at early planning stages and a higher accuracy with more input data at later stages of the building process.
7. The next version of the IFC should include the possibility of exchanging models as machine code.

These recommendations focus on making the evaluation of active building envelopes more accurate and cheaper.

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