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Photovoltaic collectors efficiency according to their integration in buildings

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Abstract

A model for building integrated photovoltaic systems has been developed and implemented in a dynamic simulation tool. This tool takes into account the thermal interactions between the PV collector and the building. The influence of the type of integration upon the PV collector efficiency has been evaluated and hybrid PV/air collectors have been studied. An overall efficiency is defined, including the production of electricity and heat. A case study has been performed on two different typical buildings. In the case of a multi-crystalline silicon PV collector integrated on the roof of a single family house located in Paris, the efficiency of unventilated PV modules fixed on the roof is 14%. If the PV collector is used to preheat the ventilation air, the efficiency reaches 20%. A proper building integration also improves the environmental balance of PV technologies over their life cycle.

Keywords: Building integrated photovoltaic; Simulation tool; Environmental life cycle assessment

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1. Introduction

During the last years, the integration of photovoltaic (PV) collectors in buildings has progressed and new components have been successfully implemented in architecture (IEA, 1996; IEA, 2000). PV modules can be used as a cover material onto a roof or a façade, integrated in chimneys or over a roof. Semi-transparent collectors can be used to cover an atrium. Beyond the aesthetic aspect, the aim of building integration is to reduce the pay back time of PV systems. From the energy point of view, this can be achieved by improving the efficiency of PV collectors.

The aim of this paper is to show how the type of integration can influence the efficiency of PV collectors.

A brief description of the simulation tool will be given first. Then we focus on the modelling of building integrated PV collectors. At last, the application of the model will be illustrated by studying PV collectors integrated in two typical residential buildings in France.

2. The simulation tool

The thermal simulation tool of multi-zone buildings named COMFIE (Peuportier and Blanc Sommereux,

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Nomenclature

C_f	primary energy conversion factor, –
C_p	specific heat, J kg^{-1} K^{-1}
E	energy, kW h
G	global irradiance, W m^{-2}
H	irradiation, kW h
h	heat transfer coefficient, W m^{-2} K^{-1}
I	current, A
k	Boltzmann constant, J K^{-1}
L	height, m
$\dot{m}$	mass flow rate, kg s^{-1}
Noct	normal operating cell temperature, K
$\dot{Q}$	heat flow rate, W
q''	heat flux, W m^{-2}
q	elementary charge, eV
R	thermal resistance, W^{-1} m^2 K
T	temperature, K
U	heat loss coefficient, W m^{-2} K^{-1}
V	voltage, V
w	width, m
α	absorption factor, –
η	efficiency, –
ξ	transparency, –
τ	transmittance, –
Subscripts	
ext	external
f	fluid
ov	overall
pv	photovoltaic
th	thermal
z, adj	adjacent zone

1990) allows heating and cooling loads as well as temperature profiles in different zones to be evaluated. The program has been developed using an object oriented approach, allowing modules to be linked to the core of the program. These modules can represent solar components, and especially building integrated photovoltaic systems.

During the simulation, parameters are exchanged between each module and the core of the program: zone temperatures and energy produced by the PV collector for example (see Fig. 1). In this way, the thermal interaction between photovoltaic collectors and the building can be taken into account. The heat capacitance of the PV collector is considered negligible compared to the thermal mass of the building walls. Hourly climatic data is used, but a smaller time step (e.g., 15 min) is generally needed to model the dynamic behaviour of the building, the output being integrated over 1 h. Faster dynamic evolution (e.g., sun and cloud alternation) is not accounted for.

The simulation tool can be described according to its three essential steps: input, dynamic simulation, and output.

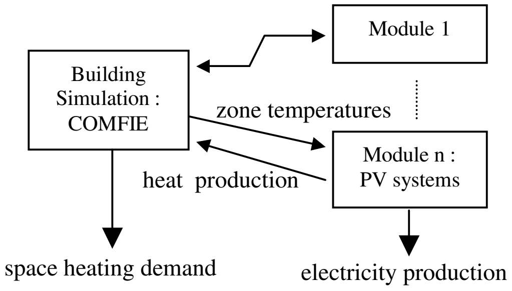

Fig. 1. Overview of the simulation tool.

First, the building envelope model is defined by its geometry and elements (wall compositions, window types, etc.). If a photovoltaic collector is integrated into the envelope, its thermo-physical parameters must be taken into account. The main parameters are the emission and absorption coefficients, and for a PV glazing the U (heat losses) and g (solar transmittance) values.

After describing the building envelope, the photovoltaic system is defined. The system consists of two components: the PV collector itself, and the inverter. Although the simulation tool is able to simulate standalone PV systems, we focus in this article on grid-connected systems (i.e., without battery). As developed in the next paragraph, electrical, geometrical and thermophysical parameters are needed.

Once the project is defined, the simulation is performed using hourly meteorological data. Concerning the building, the program calculates the energy loads of the building, and the hourly temperatures in the different zones. Concerning the PV system, the program calculates the energy produced by the system, and can generate hourly outputs like the electricity produced and the incident radiation on the PV collector.

3. Building integrated photovoltaic systems modelling

The model presented in this paper has been developed with the aim of taking into account many types of integration, according to three main classes of models: integration without thermal interaction with the building, integration without air gap and integration with ventilated air gap.