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Review

A nodal thermal model for photovoltaic systems: Impact on building temperature fields and elements of validation for tropical and humid climatic conditions

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ABSTRACT

This article deals with both an experimental study and a numerical model of the thermal behaviour of a building whose roof is equipped with photovoltaic panels (PV panels). The aim of this study is to show the impact of the PV panels in terms of level of insulation or solar protection for the building. Contrary to existing models, the one presented here will allow us to determine both the temperature field of the building and the electric production of the PV array. Moreover, an experimental study has been conducted in La Reunion Island, where the climate is tropical and humid, with a strong solar radiation. In such conditions, it is important to minimise the thermal load through the roof of the building. The thermal model is integrated in a building simulation code and is able to predict the thermal impact of PV panels installed on buildings in several configurations and also their production of electricity. Basically, the PV panel is considered as a complex wall within which coupled heat transfer occurs. Conduction, convection and radiation heat transfer equations are solved simultaneously to simulate the global thermal behaviour of the building envelope including the PV panels; this is an approach we call '*integrated modelling*' of PV panels. The experimental study is used to give elements of validation for the numerical model and a sensitivity analysis has been run to put in evidence the governing parameters. It has been shown that the radiative properties of the PV panel have a great impact on the temperature field of the tested building and the determination of these parameters has to be taken with care.

Contents

1. Introduction

Current craze for solar energy comes from the fact that it is renewable. Indeed, Europe and the major states of the planet promote the use of clean energies (which emit little greenhouse

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effect gases), and favour those that use them. There was recently a meeting organized by the French government (known as the Grain of environment) whose purpose was to fix objectives of the country in the fields of Energy and Environment. The aim is to promote the use of renewable energies, and particularly the solar energy.

La Reunion Island is already an example in this field, as it is being the first French Department to use solar energy with both the thermal collectors (for the production of sanitary warm water) and the photovoltaic panels (for the production of electricity). An important objective for the Island is to reach autonomy in energy by 2025. To extend the use of PV panels, studies have been set up whose purpose is to propose additional arguments as will be presented in this paper. La Reunion Island being a French overseas department with tropical and humid meteorological conditions, it is therefore an ideal location for experiments to be made.

As far as tropical climates are concerned, studies have already shown that the main effect which is responsible of the increase of temperature in buildings is due to the solar radiation (20% of thermal loads). The most important part of this energy passes through the roof of the building, because it is the part the most exposed to the sun. Until now, this problem has been solved by adding insulation to the roof (usually between the ceiling and the roof). Another solution was brought to light: the use of a PV panel as a replacement of the insulation material, which will thus exploit both its capacity to produce electricity and its ability to protect the roof against solar loads.

In the study presented here, the interest is to quantify the insulation effect (or thermal impact) of a PV panel on a test building to put in evidence the associated comfort conditions. This first approach consists in developing a numeric thermal model of PV panels, integrated into a building simulation code, and conducting an experimental study of a building whose roof is equipped with a PV panel. The results of the numerical model and collected data of this experimental study will then be compared into a validation step of the whole model.

2. Integrated thermal modelling of PV panels

2.1. Presentation of the building simulation code ISOLAB

The proposed model of PV panel was integrated into a building simulation code named *ISOLAB*. This code allows the prediction of the building temperature field by describing the building and the climate of its location. Implemented with MATLAB platform, the *ISOLAB* code is actually dedicated to models testing before integration in the CODYRUN software, developed and distributed at the Building Physics and Systems Laboratory of the University of La Reunion Island. Until now, it has not been possible to predict energy exchanges between the building roof and the PV panel, as well as PV electricity production. In terms of technical description of the codes (CODYRUN and *ISOLAB*), they are part of the thermo-aeraulic building simulation codes, and are based on a nodal description of buildings with a one-dimensional modelling of the thermal phenomena arising in the walls comprising the building.

The addition of the PV panel model to *ISOLAB* is made by considering it as a complex multi layer wall. Usually, the building is described by defining all walls that compose it both from the point of view of thermo-physical properties and model choices. Each wall is considered as an assembly of one or several layers, some of which can be of fluid nature. However, there is a major difference between a traditional typical wall and a PV panel: a PV panel is composed by many semi-transparent layers (silicon, glass, ...) and sometimes by reflective layers, and is thus concerned by advanced thermal physical phenomena. The PV panel is described as a specific wall, and the possibility is offered to consider every kind of possible integration (see Refs. [1,2,5] and Fig. 1).

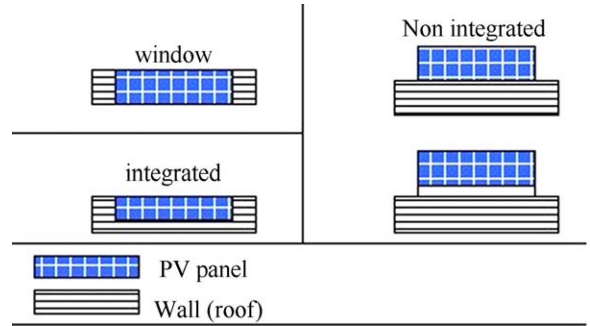

Fig. 1. Typical integrations of PV panel installation.

In order to calculate the building thermal field, thermal and geometrical properties of the building are entered in the code. If PV panels are installed on the building, they are described according to thermal and electrical properties, and the type of integration on the building. Then a meteorological database is associated to the building. During the simulation, if the *ISOLAB* code detects a PV panel on the building, the PV model is used to generate the matrix that described thermal exchanges. This matrix is added to the traditional matrix system of the whole building (see Fig. 2).

In a PV panel, there are radiative exchanges through semi-transparent layers, while in traditional walls, energy exchanges are made mostly by conduction. To model radiative exchanges, a simple model was used to express energy losses of each side of the semi-transparent layers. Then those losses are taken into account by adding a specific term into the equation system that describes thermal exchanges within the building (see Ref. [4]).

The equation system can be written using the state system formalism:

$$[A]_i \cdot [T]^t = [A]_e \cdot [T]^{t+1} + [B] \tag{1}$$

Matrixes $[A]_i$ and $[A]_e$ describe the composition of the various materials constituting the building, and matrix $[B]$ corresponds to outside or internal solicitations of the system. Matrixes $[T]^t$ and $[T]^{t+1}$ contain all nodes temperatures of all walls for two successive time steps (t and $t + \mathrm{d}t$).

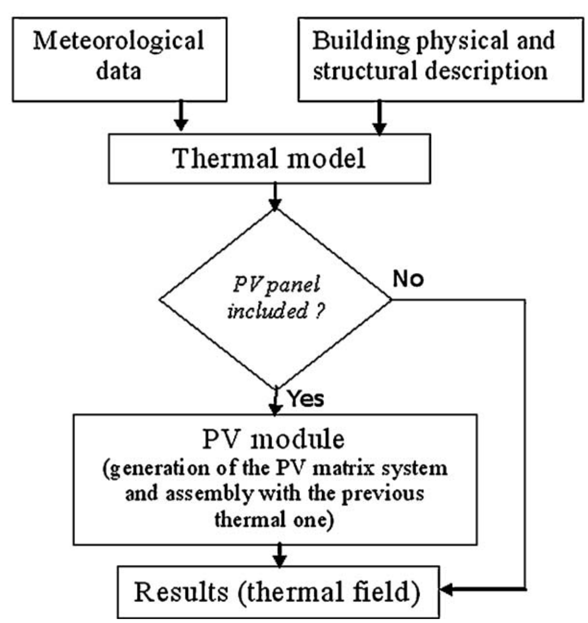

Fig. 2. Integration of the PV model to the existing Isolab code (Ref. [1]).