Modelling Active Building Elements with Special Materials

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Summary

This report details the addition of the *Special materials* function to ESP-r. The workings of the special materials code is described as well as information on the various entities which have (or can) be modelled using the special materials technique. Finally an example is given where a special materials function is used in the simulation of a photovoltaic facade on a PASSYS test cell.

The Authors

Nicolas Kelly and Mark Evans are two of several post graduate students active within the Energy Systems Research Unit (ESRU). Nicolas Kelly has a first degree in Environmental Engineering and is researching simulation of combined thermal and electrical systems while Mark Evans holds a first degree in Electrical Engineering and is currently working on aspects of renewable energy integration.

1. Introduction

Special materials were introduced to ESP-r as a means of modelling *active building elements* i.e those building elements which change their thermophysical properties or alter their associated energy flows (or both) in response to some external excitation. There is a vast range of such elements, some examples being; electrochromc, thermochromic, photochromatic and liquid crystal glazings, photovoltaics, phase change materials, light pipes and heat pipes etc. Many of these components form elements of what has become known as the *intelligent building facade* and, in general, are either passive or active solar elements.

2. Operation of Special Materials

Special materials functions apply to a particular node within a multi-layer construction. The layer containing the node is selected by the modeller and will have some relevance to the special material being modelled. As an example consider a thermochromic glass (Fig 2.1) located in a double glazed window. The transparency of the thermochromic glass is dependent on the glass temperature. In this case the thermochromic glass is the first layer of the double glazing system, the relevant node being the central node of the first layer (for 3 layers per node) the relevant node is therefore node 2. In this case the optical properties of the glazing system will be a function of the temperature of the special material node in the thermochromic layer.
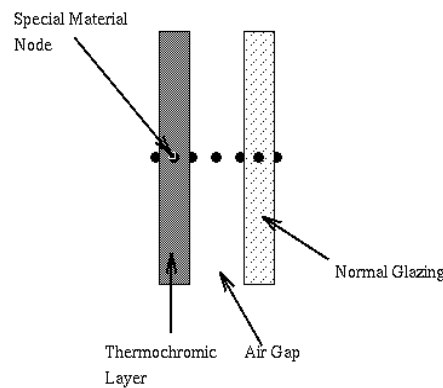

Figure 2.1 ESP-r Cross-section of a thermochromic glazing

3. Defining special materials in an ESP-r model

Definition of special materials is done in the project manager. In geometry creation special materials are entered as special surface attributes i.e either 'opaque + special properties' or 'transparent + special properties'. The user is then asked to select the layer in the surface which contains the special material and also select the special material type from a menu. According to the special material chosen the user must enter a number of data items associated with that particular special material (these are shown in the appendix). The process can be repeated for up-to 20 special material nodes.

At the end of the problem definition session a special material file containing special material node locations, types and associated data is written, in subsequent problem definitions this file can be re-read and edited at the users discretion.

4. Special materials within bps

At the begining of a simulation run the user has the option of activating the special materials algorithms within bps. This is done by setting the 'special facade materials' option within simulation toggles to >> ON. The user is then prompted for the name of the special materials file associated with the problem. Once this is correctly done the program will read in the file, reporting if any errors have been discovered in the data.
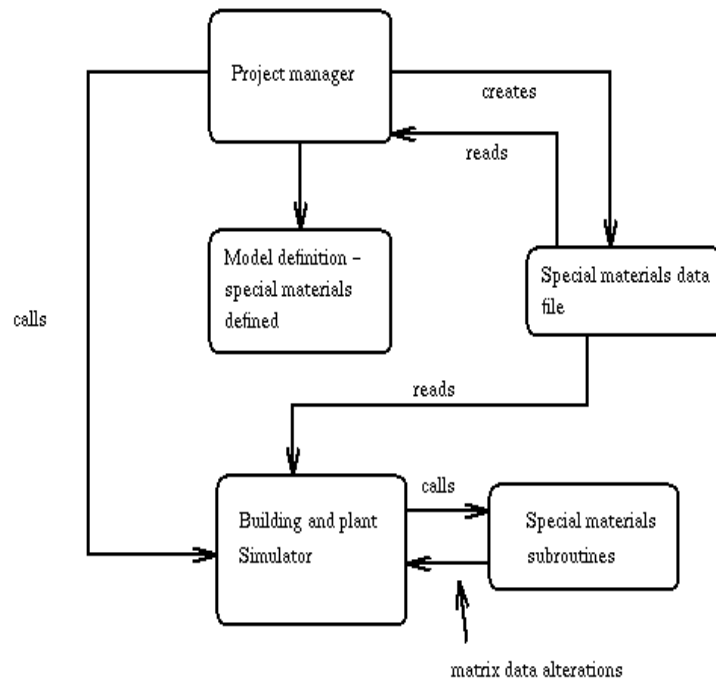
Figure 3.1 Special materials in esp-r

Special materials operate on the principle of modification of the relevant nodal matrix coefficients prior to matrix formulation and solution. In other words special materials work one time-step in arrears, using previously calculated nodal values to modify the future time step nodal coefficients (fig 4.1) .

Special materials subroutines read in relevant nodal information which is used to calculate an alteration in the matrix set-up. The subroutine called is determined by the type of the special material. At present three types of special material are active; crystalline silicon PV, amorphous silicon PV and thermochromic glazing.
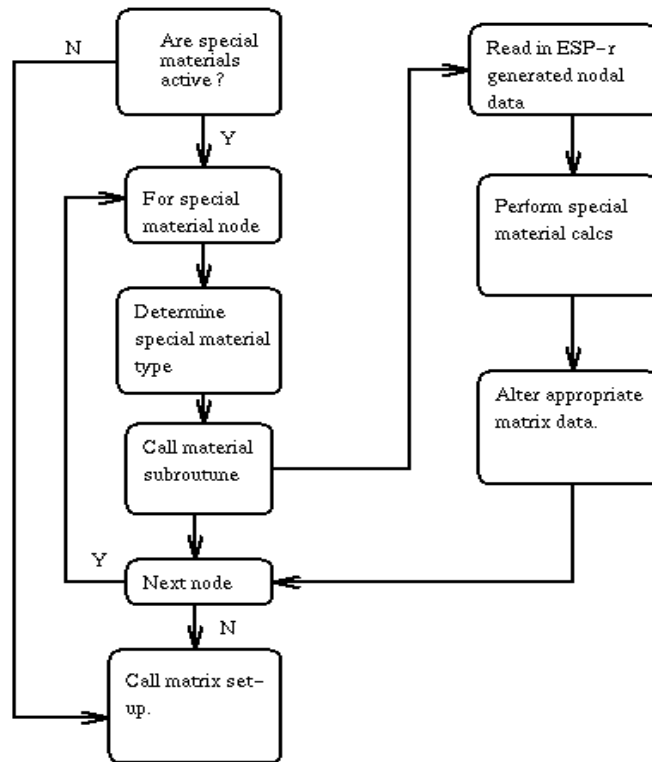
Figure 4.1 Special materials algorithm operating in bps

5. Example of special materials operation

5.1. Amorphus silicon PV facade

As an example of the use of a special material consider the use of a PV facade in a PASSYS test cell (as shown in fig5.1).
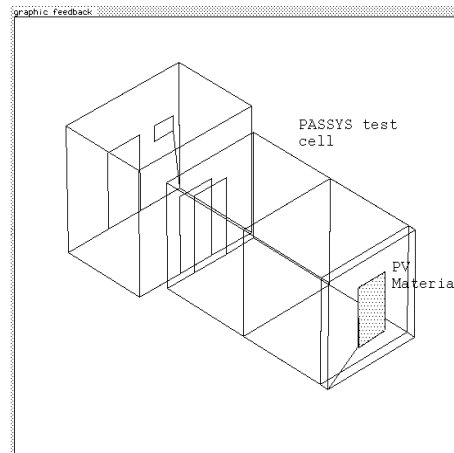

Figure 5.1 PV facade mounted on PASSYS test cell

For this problem a transparent construction called PV_panel and a corresponding ESP-r optical property database entry were created to represent the physical construction of the PV panel (shown in fig 5.2).
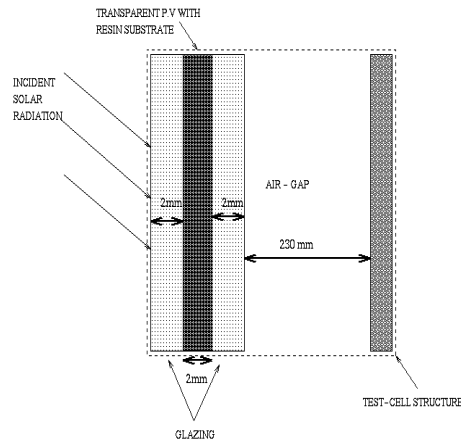
Figure 5.2 Cross section of PV facade

The special materials node was placed at the outer node in the resin substrate layer. The special materials file then picks up this nodal temperature and the incident solar radiation on the glazing system. These two variables along with the special materials data are used to calculate the panel power output at each simulation timestep. The power output for the cell is then subtracted from the nodal absorption of of the incident beam. This modification reflects the fact when a PV panel is exposed to solar radiation it's temperature is lower when producing power i.e some of absorbed solar radiation is converted to electrical power rather than manifesting itself as a heat gain. For a detailed description of the operation of the PV cell special material
 algorithm see the appendices.

The output of the special materials subroutine (in the case of the P.V panel the power production) is output to an asciII results file capable of importation into a 3rd party graphing package such as *xvgr*
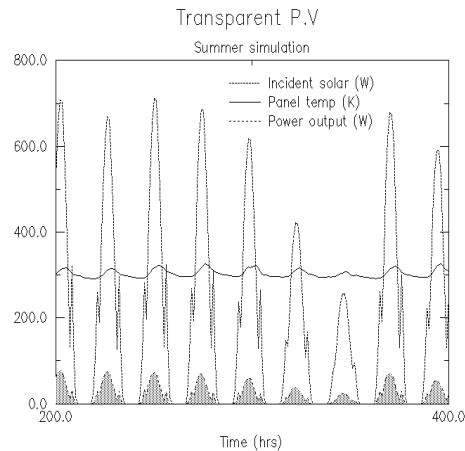

Figure 5.3 Output from simulation

The simulation was run over the perion 7th - 13th July using a Kew '67 climate data set. Panel data was taken from the manufacturer's data sheet.

6. Appendix

6.1. PV materials

The model implemented in ESP-r to calculate the output from a PV panel is represented as a set of series (n) and parallel (m) connected p-n junctions or cells. This is shown in figure 6.1
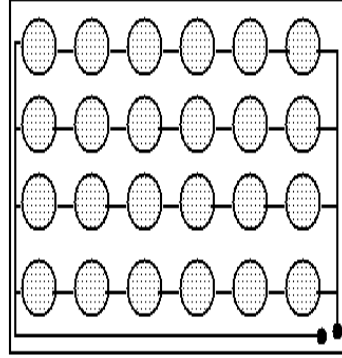

Figure 6.1 Photovoltaic panel

In this case $n = 6$ and $m = 4$

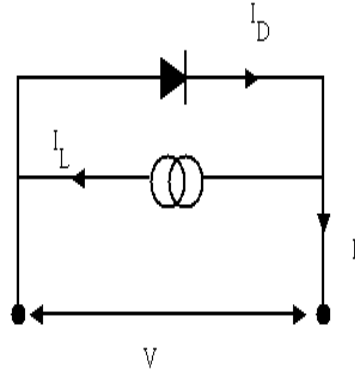Each of tne p-n junctions is represented by the following equivalent circuit.

Figure6.1 Equivalent circuit for a p-n junction exposed to light

For this equivalent circuit a set of equations have been derived that allow the operation of a single junction, and hence a panel to be simulated. Data for the can be obtained from panel makers data sheets. The equation set for a panel with maximum power point tracking.

$$DF = \frac{\left(\dfrac{e}{kT_{ref}}\right)\left(V_{mp} - \dfrac{V_{oc}}{n}\right)}{\ln\left(\dfrac{I_{sc} - I_{mp}}{I_{sc}}\right)} \tag{A.1}$$

$$I_o = 2^{\frac{(T-T_{ref})}{10}} \frac{-\dfrac{I_{sc}}{m}}{\left[\exp\left(\dfrac{e\,\dfrac{V_{oc}}{n}}{kT_{ref}\,DF}\right) - 1\right]} \tag{A.2}$$

$$I_L = \frac{Q}{Q_{ref}} \frac{I_{sc}}{m} \tag{A.3}$$

$$1 + \frac{I_L}{I_o} = \exp\left(\frac{eV_{mpp}}{kT\ DF}\right)\left[1 + \frac{eV_{mpp}}{kT\ DF}\right] \tag{A.4}$$

$$P = \left(V_{mpp}.\,I_o\left[\exp\left(\frac{eV_{mpp}}{kT\ DF} - 1\right)\right] - V_{mpp}.\,I_L\right) n.\,m.\,N_{pnnls} \tag{A.5}$$

It should be noted that equation A.4 requires an iterative solution to find the maximum power point voltage.

The following nomenclature has been used:

V_{oc} - Open circuit voltage (at reference values)

I_{sc} - Short circuit voltage (at reference values)

V_{mp} - Voltage at maximum power point (at reference values)

I_{mp} - Current at maximum power point (at reference values)

Q_{ref} - Reference solar insolation

T_{ref} - Reference temperature

n, m - Number of series parallel connected cells

N_{pnnls} - Number of panels

DF - Diode factor

I_o - Diode current

I_L - Light generated current

V_{mpp} - Voltage at maximum power point (at current timestep)

P - Panel power output

e - Charge on an electron

k - Boltzman constant

T - Panel temperature

7. Data requirements for special materials (crystalline and amorphous)

7.1. PV

1 - Open circuit voltage. (V)

2 - Short circuit current. (I)

3 - Reference insolation. (W)

4 - Reference temperature. (K)

5 - Number of series connected cells (not panels) (-)

6 - Number of parallel connected branches. (-)

7 - Number of panels in surface. (-)

7.2. Photochromic glazing

1 - Switching temperature

8. References

Buresch M., *Photovoltaic Energy Systems - Design and Installation* McGraw-Hill, New York, 1983.