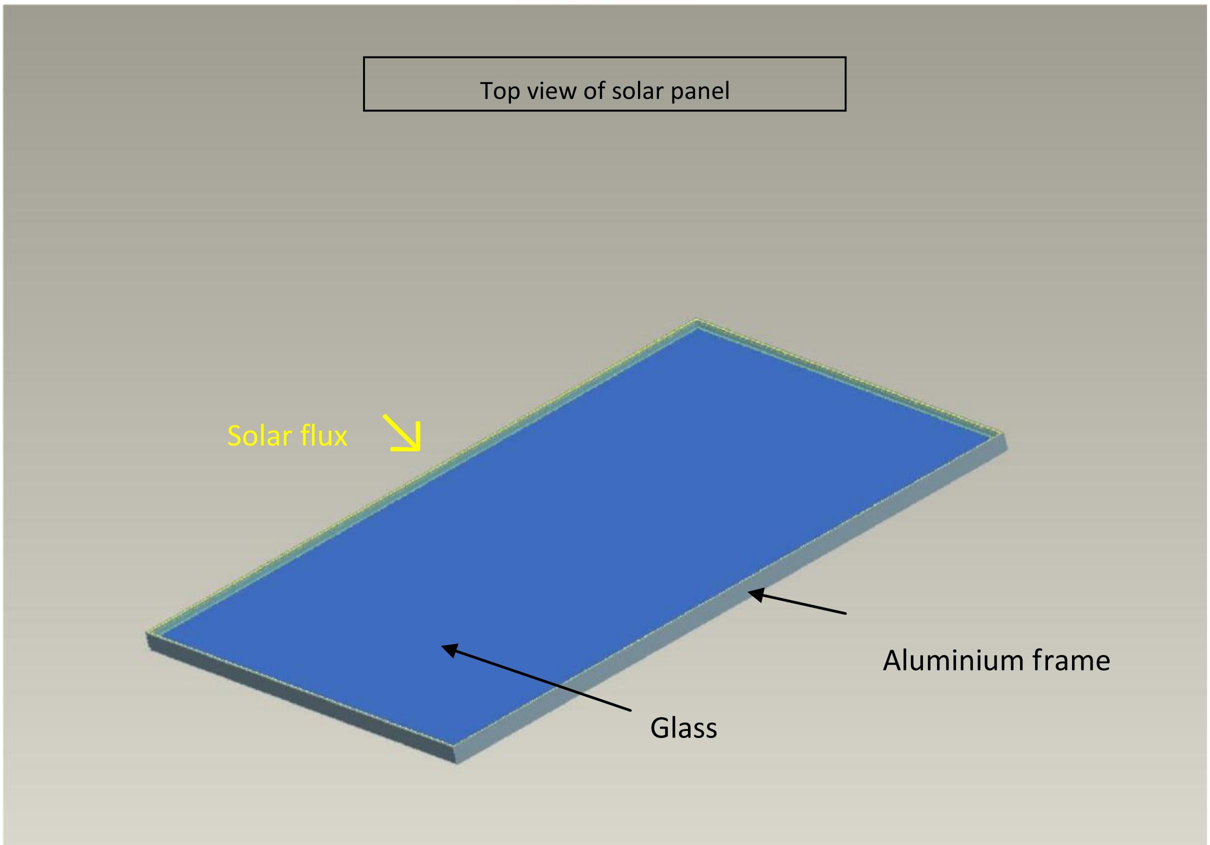
CHAM Limited

Pioneering CFD Software for Education & Industry

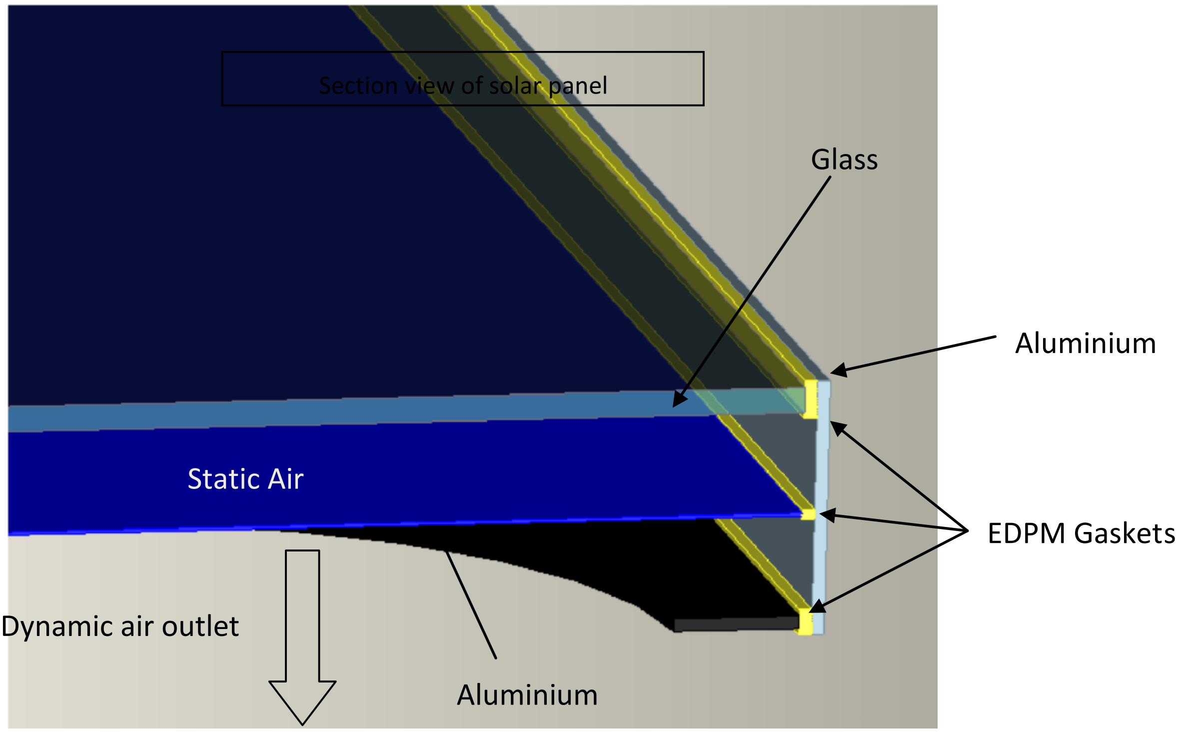
CHAM Case Study – Heat Transfer within a Solar Panel

PHOENICS demonstration

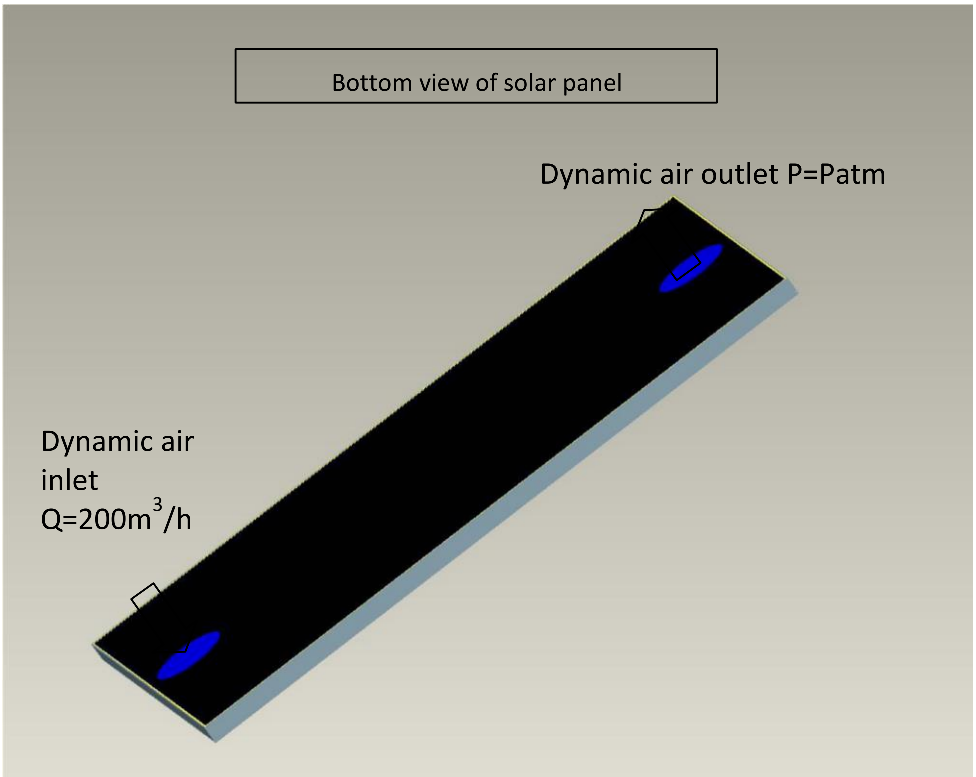
PHOENICS has been applied to the simulation of heat transfer within a solar panel design on behalf of the LE2M Laboratory of ICAM, Nantes, France. The panel is assumed to be horizontal and consists of three layers; glass, collector and backboard, with air spaces between. The aim of the panel is to warm air through solar irradiation. The glass and collector gather heat by the "greenhouse effect", and this heat is transferred to air flowing through the space behind the collector. In this case study, a CFD model was constructed to simulate the convection, conduction and radiation heat transfer processes in the panel.



Solar panel top with (transparent blue) glass and grey aluminium frame.
The Sun's radiation is perpendicular to the glass plane.



This cross-section shows the transparent glass, the aluminium collector (blue), the ABS back board (black), three EPDM gaskets (yellow) and the aluminium frame (grey). There is static air between the glass and the collector. There is dynamic air between the collector and the ABS back board.

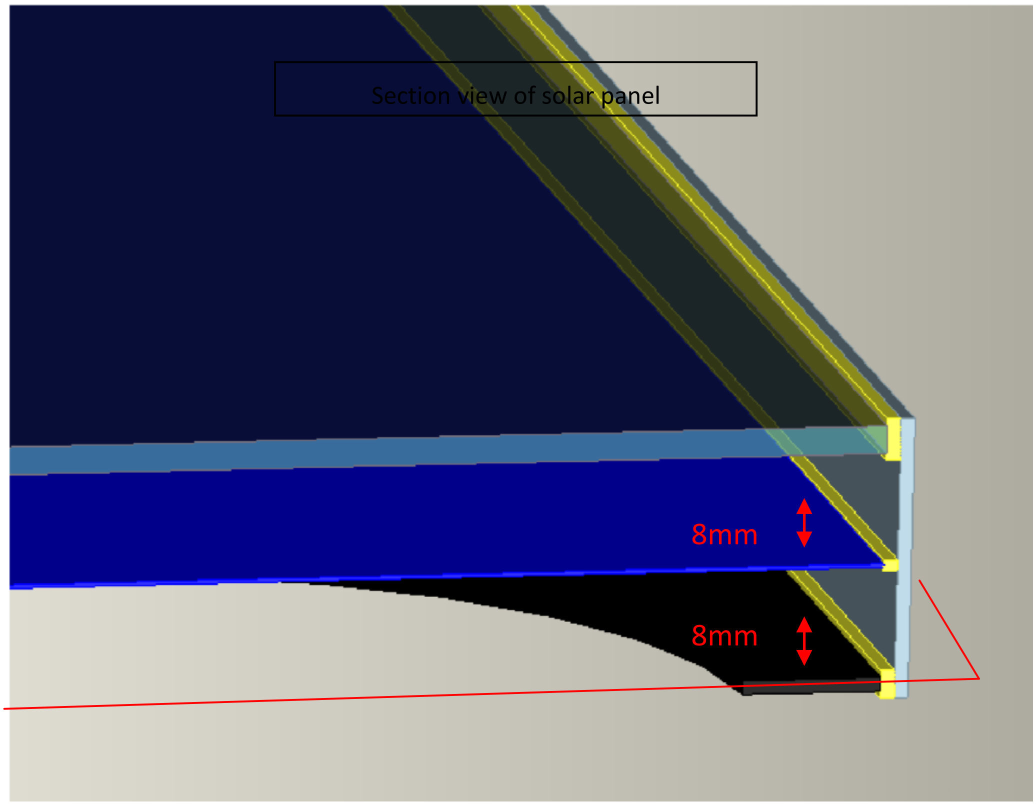


ABS back board (black), the aluminium collector (blue) and the aluminium frame (grey). The two holes in the ABS backboard represent the inlet and the outlet for the dynamic air.

Although the solar panel might appear to be a simple device, it involves a relatively complex set of heat-transfer processes, namely:

- solar gain on the exterior surface of the glass, where some of the solar energy is absorbed;
- transmission of the remaining solar energy through the glass and static air;
- consequent solar gain on the upper surface of the collector;
- heat loss by radiation from the glass external surface;
- heat conduction through the glass and through the collector;
- exchange of thermal radiation across the static air space, between the glass and the collector;
- exchange of thermal radiation across the dynamic air space, between the collector and the backboard;
- heat conduction in the backboard;
- heat conduction from the static air to the dynamic air via the frame, bypassing the collector;
- transfer of heat by convection from the collector and the backboard to the dynamic air; and,
- heat loss from the backboard external surface.

All these processes are represented in the model, with visible and infra-red radiation distinguished where this is relevant. The objective of the study is to ascertain the outlet temperature of the dynamic air delivered by the solar panel, from which the panel efficiency can be determined, and the temperature distributions through the glass, collector, and backboard.



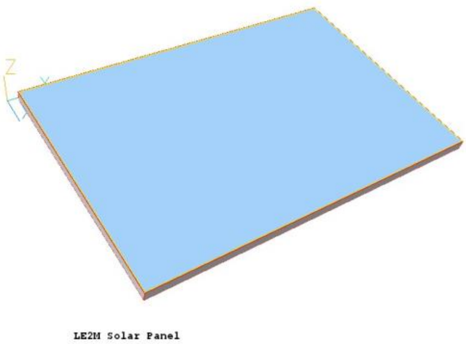
The PHOENICS model solves conservation equations for mass, momentum in the dynamic air, and thermal energy. The operational parameters of the solar panel specified by Laboratory LE2M are used in specifying the model, which was created using PHOENICS from CAD imported from PTC's ProEngineer. In view of the regularity of the geometric shape, the PARSOL (PARtial SOLid) cut-cell feature is not employed.

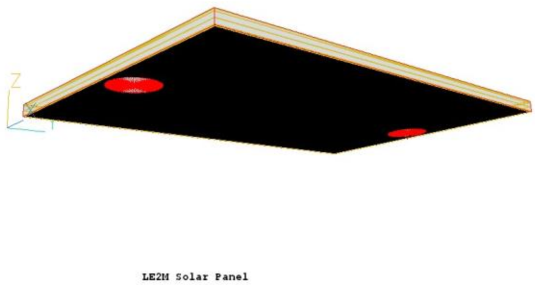
The physics of the solar panel require that visible and infra-red radiation be treated separately, and that provision be made for the absorptivity of a surface to be different from its emissivity. The glass emissivity and the absorptivity and transmissivity, for visible and for infra-red, must be specified in the model. Similar parameters (excepting transmissivity) are required for the upper and lower surfaces of the collector and for the backboard. These specific requirements do not fall within the standard capabilities of the default PHOENICS radiation model, IMMERSOL. Nevertheless, a bespoke model was readily introduced, based on radiation between flat plates was incorporated, using one of the user-programmable features of PHOENICS, called 'GROUND'.

The incoming solar radiation flux was specified as 1000 W/m^2 direct plus 800 W/m^2 diffuse. It is assumed that for each of these, one third of this radiation is in the visible spectrum, and two-thirds is infra-red.

The mesh size used was 67 x 58 x 50 and the run time took only 15 minutes on a single3GHz processor to reach full convergence. The model predicts a mean outlet air temperature of 38.3˚C, corresponding to a heat gain in the air of 1224W. The predicted overall efficiency of the panel is therefore 68%. Interesting information to be gleaned from the model includes individual radiative heat fluxes within the system. Thus, for example, the radiation flux between the glass and the collector is 630W, and between the collector and the backboard 510W. 180W is lost by re-radiation from the glass, and 115W is lost by radiation from the rear of the backboard.

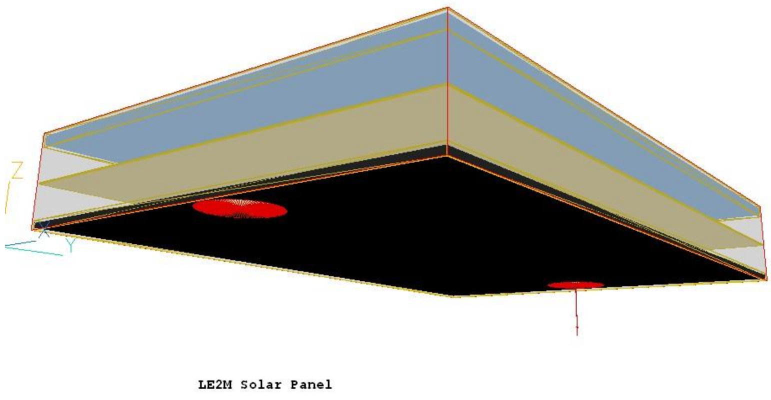
It will be seen from the plots below that there is significant non-uniformity in the temperature patterns; the collector is significantly hotter on the side to which the air is blowing. These types of additional information could be helpful to a designer by offering a deeper understanding of the operation of the system as a whole, enabling him to identify aspects where improvements may be possible.





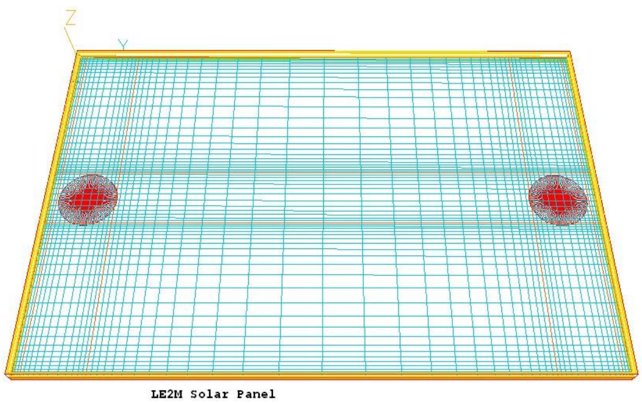
Solar panel geometry Solar panel geometry displayed in PHOENICS VR underside

Editor



Solar panel geometry

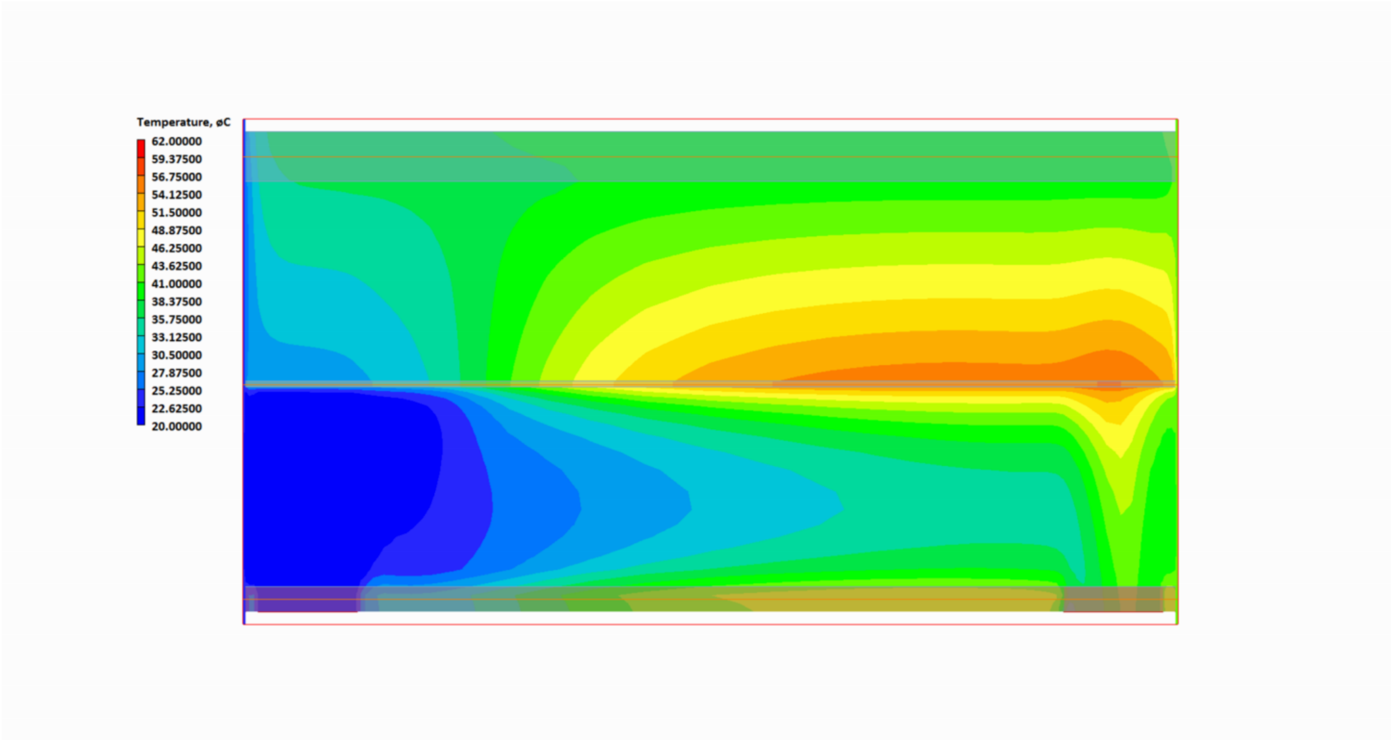
expanded view



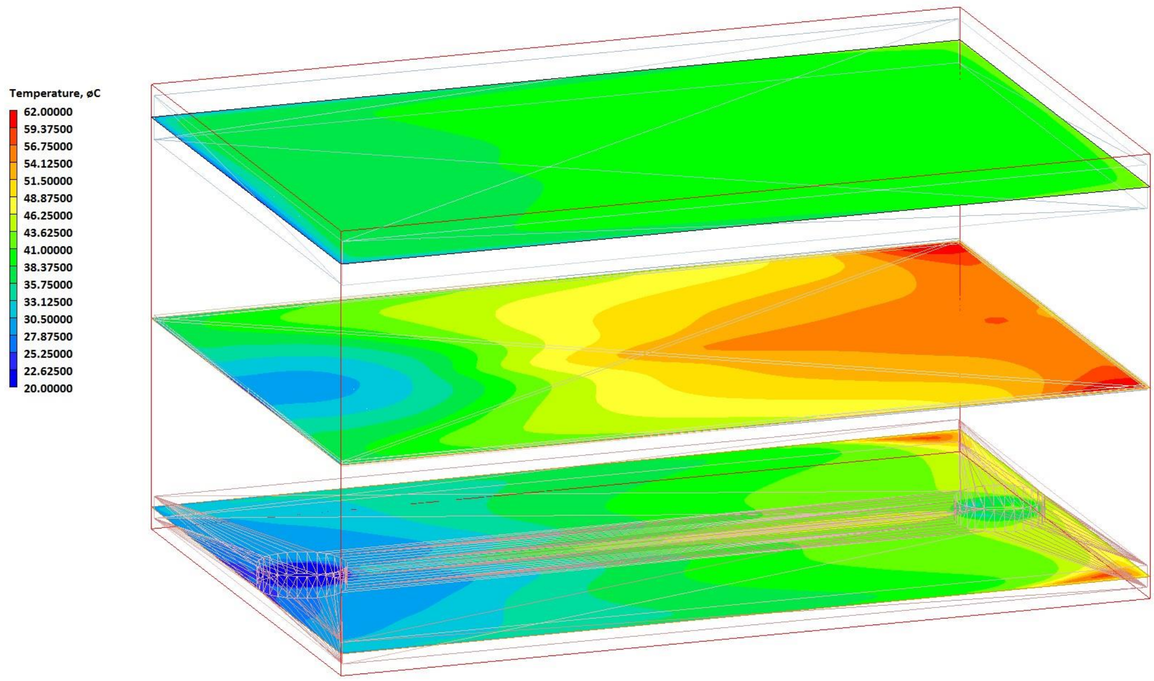
Computational mesh

<u>Results</u>

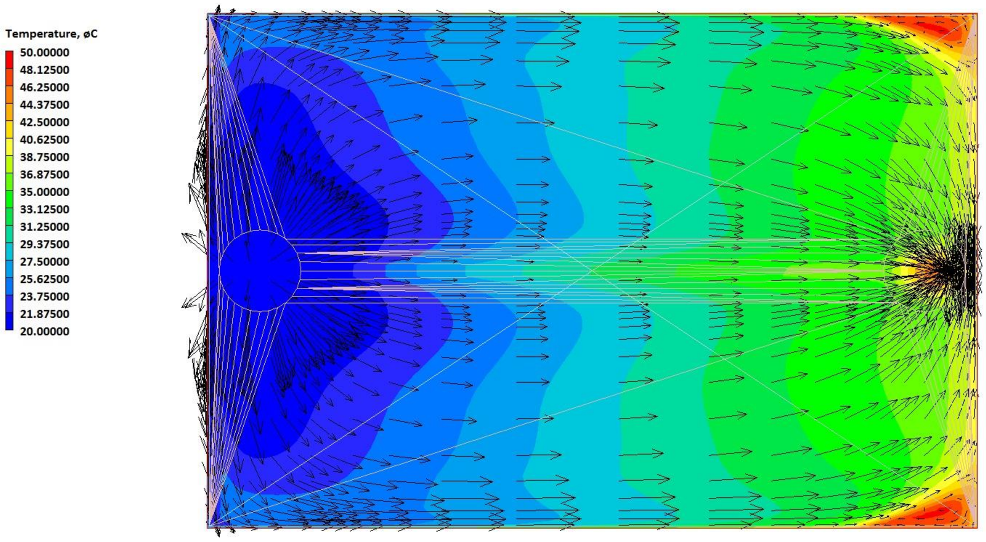
The following images illustrate the temperature distribution in the panel; note that the first two images are stretched 20x vertically for clarity.



Vertical temperature distribution on centre plane



Temperatures on glass, collector and backboard



Temperature and velocity vectors in the dynamic air space

It is clear from these plots that the airflow beneath the collector causes the temperature distribution on the collector to be significantly non-uniform. This in turn will imply that the radiant heat flux distributions within the panel are highly non-uniform. This complexity shows the benefits of using fully-configured CFD software to model heat transfer processes within the panel.

Conclusion

This study has demonstrated the ability of PHOENICS to model the complex heat-transfer and air flow processes in the solar panel, and to predict the efficiency of the panel as measured by the air outflow temperature. The model forms the basis of a useful design tool for predicting the effects of geometric parameters and the material properties on the performance of the panel, hence enabling an optimized design to be achieved.

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