International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:5, No:1, 2011

Computational Study of Improving the Efficiency of Photovoltaic Panels in the UAE

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***Abstract*—**Various solar energy technologies exist and they have different application techniques in the generation of electrical power. The widespread use of photovoltaic (PV) modules in such technologies has been limited by relatively high costs and low efficiencies. The efficiency of PV panels decreases as the operating temperatures increase. This is due to the affect of solar intensity and ambient temperature. In this work, Computational Fluid Dynamics (CFD) was used to model the heat transfer from a standard PV panel and thus determine the rate of dissipation of heat. To accurately model the specific climatic conditions of the United Arab Emirates (UAE), a case study of a new build green building in Dubai was used. A finned heat pipe arrangement is proposed and analyzed to determine the improved heat dissipation and thus improved performance efficiency of the PV panel. A prototype of the arrangement is built for experimental testing to validate the CFD modeling and proof of concept.

***Keywords*—**Computational Fluid Dynamics, Improving Efficiency, Photovoltaic (PV) Panels, Heat-pipe

I. Introduction

EXTACTED from news article, “the United Arab Emirates (UAE) is situated on huge reserves of oil; proven oil reserves of their own are expected to last for another 150 years, but like most oil producing countries, the UAE should diversify its economy in order to ease its dependency.”[1] Political pressure on climate change targets drives the economic pressure. "Even under modest growth scenario, Dubai's electricity demand is expected to double by 2015, trying to stay ahead of that kind of growth is going to become more and more challenging”, said His Highness Sheikh Mohammed bin Rashid Al Maktoum.[1]

To combat these problems, the most applicable renewable energy technology in the UAE is to utilise one of its profuse natural resource’s namely, year- round sunshine. Currently energy from the sun has been used in the UAE to power parking ticket booths and to generate electricity for a few other small-scale operations. Using solar power on a large scale to elevate the energy demands, curb greenhouse gas effects and tackle climate change is now a political necessity. Recent developments in neighbouring Abu Dhabi, in the form of the city of Masdar have shown that the UAE is ready to embrace renewable energy technologies to combat global warming. Masdar (the Abu Dhabi Future Energy Company) is a versatile company advancing the growth, commercialisation and operation of renewable energy solutions and clean technologies.[2]

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Hence, the introduction of solar technologies is now more commercially viable as numerous companies are now seeking green initiatives to gain a wide range of financial incentives from the UAE government.

The efficiency of photovoltaic cells decreases as temperature increases, therefore cooling is essential at elevated illumination situations for instance concentrating systems, or hot and humid conditions. With the average temperature in the UAE reaching up to 42^0 C in the summer the cell temperature could reach up to 80^0 C which decreases the output power by up to 0.65%/K, fill factor to 0.2%/K and conversion efficiency to 0.08%/K of the PV module, above the operating temperature (Fig. 1 and 2). “The relative temperature coefficient of crystalline silicon solar panels falls in the range 0.4 – 0.6% K. 13% absolute conversion efficiency corresponds to an absolute temperature coefficient between 0.031 and 0.046% K. Therefore a reduction by 20^0C will give an increase in efficiency between 0.6 and 1%.”[3]

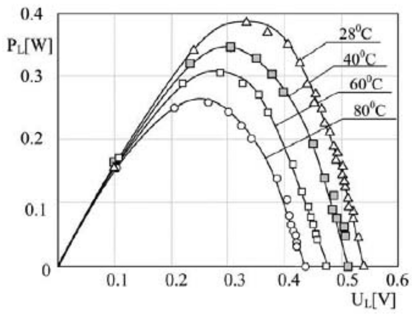


Fig. 1: Output power versus voltage at various temperatures[4]

The overall reduction in the highest possible output power (P_{max}) of a solar cell decreases as the cell temperature increase, shown in Fig. 2.

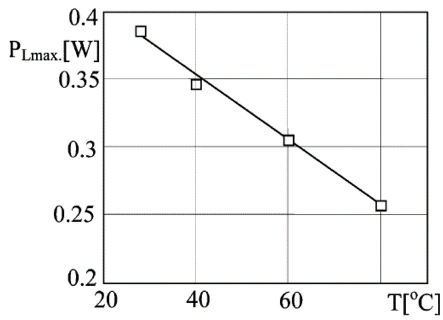


Fig. 2: Temperature dependence of the maximum power output[4]

Hence, a need exists for a passive cooling system for PV modules, which may be fabricated in a cost-effective manner. This paper uses Computational Fluid Dynamics (CFD) to analyze the performance of a finned heat pipe arrangement for cooling of a standard PV module. A scaled prototype is designed and built to validate the CFD modeling.

II. Literature Review

Beach and White [1981][5] demonstrated the utilization of copper fins soldered to a copper heat pipe, to extract heat approximately provided by 700 suns. The system was a thermosyphon pool boiler with working fluid of either acetone or water. This was only tested when oriented vertically. The temperature difference between cell and ambient air (30^0C) is used for cooling with the help of natural convection.

Farahat [2004][6] conducted a study on the orientation of solar concentrators, using maximum number of reflections to utilize the abilities of the PV panel effectively. A study was also presented comparing the cooling abilities of heat pipes to that of forced convection water-cooling system. The study concluded that the heat pipe arrangement showed significant advantage over the convection water-cooling technique.

Radziemska [2003][4] reviewed the applications for building integrated photovoltaic (PV) thermal systems and the effect of ambient temperature on photovoltaic cells. The report shows the effect of increase in cell temperature (reduced efficiency). The study also describes how extracting heat using natural or fluid circulation can lower the PV temperature. A hybrid PV/Thermal system was proposed for cooling of the PV system.

Zhao and Avedisian [2007][7] carried out experimental studies on a copper heat pipe attached to copper plate fins for cooling by forced convection. The results achieved showed good heat transfer and that maintained fin pitch could significantly increase the heat transfer; also the fins section when arranged in parallel were extremely efficient for dissipating high heat flux and powers at moderate surface temperatures.

Rodriguez [2005][8] found that due to the increase of temperature, the efficiency of PV solar cells decreases theoretical and experimental studies. The study concludes that using concentrating systems, under extraterrestrial or hot and humid conditions, it is essential to use a cooling system. Furthermore a cooling system can benefit the PV module by an increase in efficiency from 10-16%.

Liao [2007][9] conducted an experimental study on an internally finned steel-water heat pipe for its heat transfer performance. Results from the experiment compared a heat pipe, which is gravity-aided against the finned heat pipe proved an increase in heat transfer up to 50-100% for the finned heat pipe orientation.

This review summarized that methods of cooling of solar cells is important in PV panel designs, especially for roof integrated PV modules in tropical conditions. After having an understanding of solar cell temperatures and heat pipes, the incorporation of the two systems is shown to be effective. However, the efficiency of heat pipes can be increased with the help of extended surface areas, fins. Therefore, my research is focused in the arrangement of a finned heat pipe on a PV panel, specifically its application in the UAE.

III. Objective And Scope

The purpose of this research on the finned heat pipe cooling system for PV panels is to decrease the operating temperatures of the PV panels by considering low cost techniques that can decrease the and enhance its power output, by decreasing the production of heat which would be otherwise, lost. The present paper focuses on the performance of a finned heat pipe assembled onto the rear of a PV panel analyzed using CFD.

IV. Methodology

The structure of the study is shown in fig. 3.

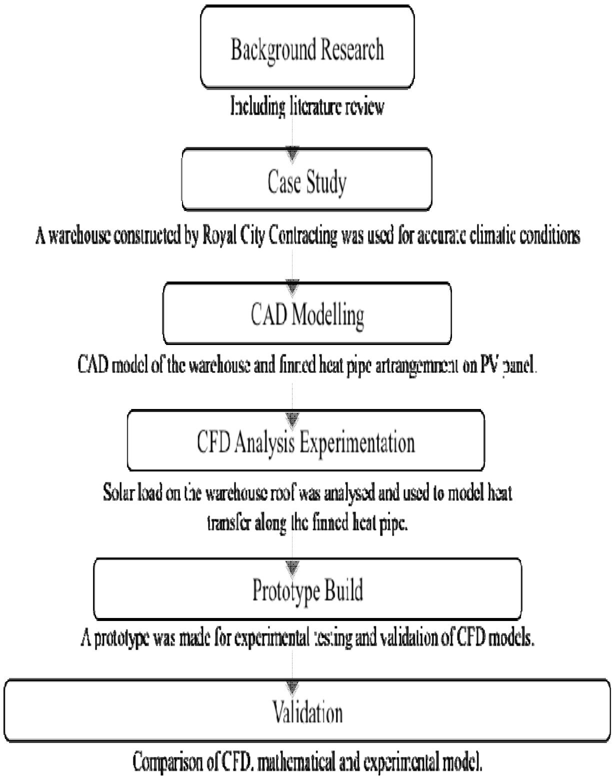


Fig. 3: Thesis Structure followed

V. Background Research

A. *Heat Produced by Photovoltaic Cells*

When PV modules are exposed to sunlight it converts only 10% to 15% of the light to electricity the rest is converted to heat. The factors that cause heating of the module include: reflection from the top surface, the electrical operating point, absorption of sunlight by parts not covered by the solar panels and low energy absorption by the cells and the packing density of the PV cells.[10]

PV panels are rated at 25^0C and isolation of 1 kW/m^2. PV panels, when utilized in the UAE operate at higher temperatures and lower isolation. The power output of PV cells can be estimated from the expected Nominal Operating Cell Temperature (NOCT), defined as the open circuit temperature of the module at 800 W/m^2 irradiance (on cell surface), air temperature of 20^0C, 1 m/s wind velocity and mounted with an open back. Ross, R.G. (1980) approximation can be used to calculate the cell temperature (T_{cell}):[11]

$$T_{Cell} = T_{Air} + \frac{NOCT - 20}{80} S \times \frac{1000}{10000} \quad (1)$$

Where:
T_{Air} = Ambient Temperature of air
S = is the isolation level

For moisture protection the solar cells are tightly encapsulated and this therefore creating complications in measuring the cell temperatures. Thus, the temperature at the rear surface of a PV panel is commonly measured instead. It is simply assumed in most applications, the cells temperatures are the same as the temperature measured at the rear surface.

B. Heat Pipes

NASA developed heat pipes especially for space applications during the early 60's. In space, (because of vacuum) it is very restricted for heat conduction. Therefore the problem was transferring temperature from the inside to the outside for space applications. Hence, it was essential to develop a fast and effective way to transport heat, without having the effect of gravity force. The concept is to create a flow field that transports heat energy from one end to another by means of convection, as heat transfer occurs much faster than conduction. More recently, heat pipes have been used in heat transfer systems, cooling of cell phones, computers and PV panels and the main advantage of heat pipes is its compactness.[12]

The basic design of the heat pipe is the circular process shown in Fig. 4. A heat pipe is a two-phase heat transfer mechanism with exceptionally efficient thermal conductivity, which consists of an insulted pipe (a wick) and a working fluid. The thermal cycle of a heat pipe is shown in fig.4, the working fluid evaporates to vapor taking in thermal energy then, and vapor travels along the cavity to the lower temperature end. Vapor condenses back to fluid and is absorbed by the wick, discharging thermal energy and the working fluid flows back to the higher temperature end.

Fins are a way of extending surfaces on compact heat exchangers, thus the heat transfer is concentrated in a small area. A finned heat pipe is employed for increasing the performance of heat pipe with evaporators and condensers creating extended areas with high thermal conductivity. The additional material increases the heat transfer and thus increases the temperature drop.

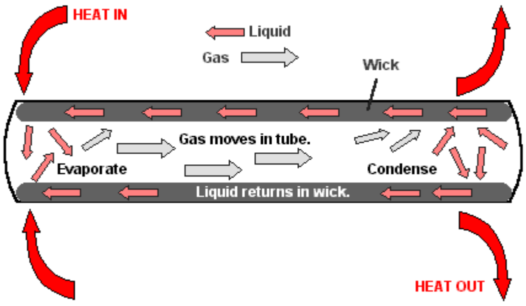


Fig. 4: Concept of a Heat Pipe [13]

C. Heat Pipe Selection

The two main assessments for the heat pipe design is the selection of the heat pipe's working fluid and envelope (wick) materials for compatibility with the heat pipe. The second main decision is the designing of the wick to cool the PV panel reliably, under any orientation and environmental conditions. The working fluid compatibility means that the fluid should not corrode or attack the wick and chemical reaction should not occur between the wick and working fluid that releases non-condensable gas (NCG). Falling under the temperature range of -20 to 100^0 C, two potential heat pipe wall and wick materials are aluminum and copper. In this study copper is selected for its higher thermal conductivity as compared to aluminum. Compatible working fluids for copper according to surveys by Dunn and Reay[14], Brennan and Kroliczek[15] and Anderson[16,17] are summarized in table 1.

TABLE I COMPATIBILITY OF COPPER WITH WORKING FLUIDS

Compatible with copper	Incompatible/Unsuitable with copper
Water Methanol, Ethanol	Ammonia Acetone

Parameters for a heat pipe cooling system:

- Reject heat by natural convection at minimal temperature difference
- Heat flux of 40W/cm2
- Ambient -20^0 C to 50^0 C

Typical results of the compatibility of working fluid and wall material are being shown in Fig. 5 and it is shown that the power output of copper/water heat pipe is six times greater than the other fluids.

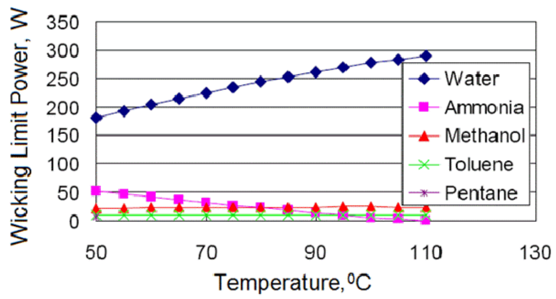


Fig. 5: Heat pipe wicking limit [3]

D. Description of the Proposed Finned Heat Pipe Arrangement

After the choice of heat pipe and working fluid, the next step was the selection of fin arrangements. In this case, the fins were arranged according to the constrained of the need to fit between the rear side of the PV panel and the result of cooling the panel. The 3D profile of the proposed arrangement used is shown in Fig. 6, 7 and 8 below. The arrangement consisted of a standard PV panel (glass, array of solar cells, aluminum frame) and the finned heat pipe assembly attached to the back of the PV panel.

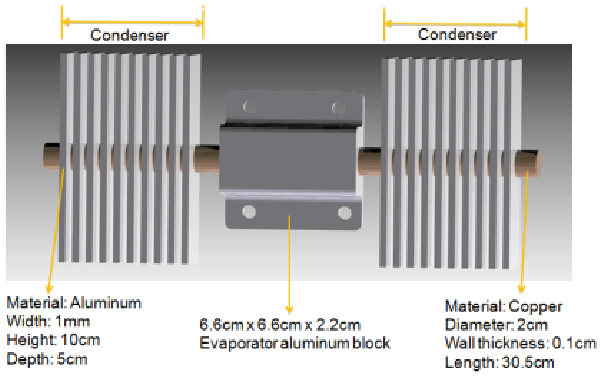


Fig. 6: Fin arrangement on heat pipe

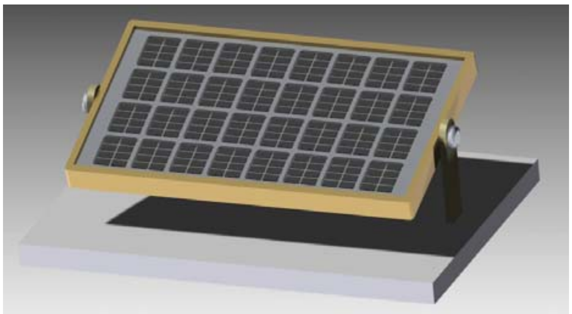


Fig. 7: Front profile of finned heat pipe assembly

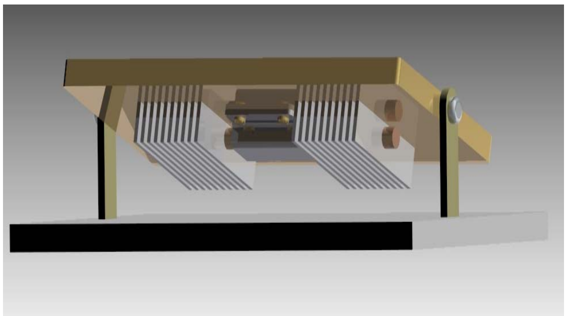


Fig. 8: Rear profile of finned heat pipe assembly

The fins attached to the heat pipe receive heat from the heat pipe by conduction and dissipates this heat with the aid of natural convection from the free stream air. The heat pipe receives heat from the solar panel via the copper saddle. Fig. 9 describes the exploded profile of the proposed finned heat pipe attached to the PV panel designed using Solid Edge ST.

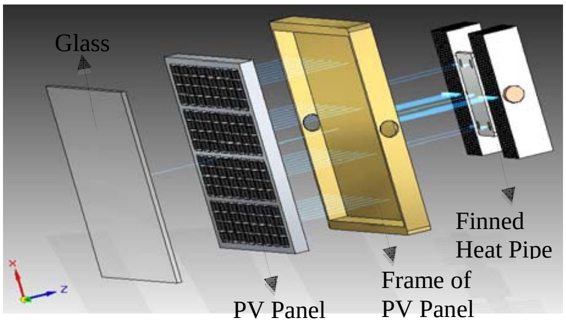


Fig. 9: Exploded view of the proposed finned heat pipe arrangement

As illustrated, the glass provides protection for the solar cells and in some cases anti-reflection coatings are applied for reduction in light scattering. The PV panel is attached to an aluminum frame to be is beneficial for the proposed finned heat pipe arrangement due to the high conductivity that aluminum can achieve. The proposed finned heat pipe arrangement consist a copper heat pipe with attached aluminum fins and an aluminum saddle acting as a heat sink for the finned heat pipe.

VI. Prototype Build

The manufacturing of the finned heat pipe arrangement prototype is shown in fig. 10. The prototype was designed and fabricated in the workshop at Heriot-Watt University Dubai Campus within the time period of 2 weeks.

In order to build the prototype of the assembly of the solar panel, the solar panel was bought from ZHONG Solar Company situated in Dubai; SPC coils provided the heat pipe. The fins were cut out of aluminum sheet metal of 1 mm thickness available in campus. The two blocks of aluminum were used to make the saddle (also obtained from the university) and a stand fabricated from cardboard.

First, 20 fins of dimension 10 cm x 5 cm were cut out of the aluminum sheet and holes were punched and then filed wider to fit the diameter of the heat pipe. Next the aluminum blocks were shaped to fit around the diameter of the heat pipe; this was done using BOXFORD CNC machining facility at University. The saddle is then screwed together with the copper heat pipe and fins added (Ten evenly placed on either side). The heat pipe assembly is then fitted to the rear of the solar panel. The entire assembly was then screwed together with the stand. Finally, the stand was spray-painted silver for a finishing touch.

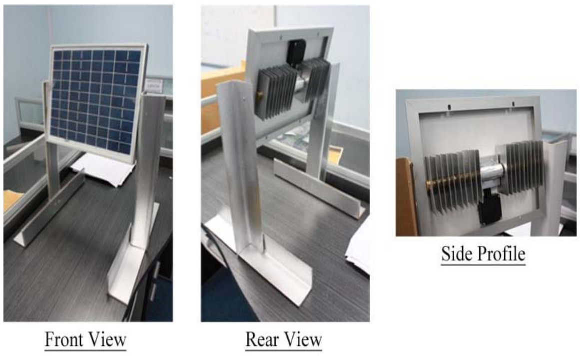


Fig. 10: Prototype built of the finned heat pipe arrangement

VII. Case Study

Based in Dubai, UAE, Royal City Contracting (RCC) L.L.C Company has 19 years experience in the field of construction and is involved in all types of building works. In c0-operation with the Emirates Green Building Council (EGBC), RCC L.L.C focuses on building sustainable structures and towards the research and development in the field of renewable systems.[18]

In support of this study, RCC L.L.C provided a case study of a warehouse (Fig. 12) at Dubai Airport Free Zone Authority (Dubai, UAE). The warehouse is constructed with a simple yet sophisticated method made of Insulated Concrete Forms (ICFs) walls which is a combination of concrete and Expanded Polystyrene (EPS). In the construction industry, ICFs is one of the fastest-growing divisions. ICFs are made of hollow blocks made of EPS, acting as the insulation for the walls, reinforced with concrete and steel, forming a well-built and energy-efficient structure, as demonstrated in Fig. 11.[19]. This is the first ICF building constructed in Dubai.

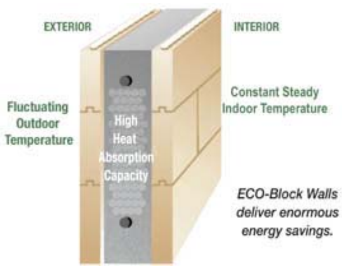


Fig. 11: Structure of Eco-Bock Wall [18]

Knowing that the operating temperature of the solar cell correlates to the isolation of the area, which in turn depends on the time of day and the season, this case study brings an extended experience and adds strength and value compared to the previous researches. With this case study the solar load on the roof was attained and used for the CFD analysis on the proposed finned heat pipe arrangement to replicate realistic environmental conditions.

Fig. 12: Dafza project, Royal City Contracting LLC[17]

A. CFD Analysis

Computational Fluid Dynamics (CFD) software is a dominant tool for fluid dynamics in academic research activities and thermal design in industrial applications. The CFD analysis presented in this study was completed using ANSYS version 12.1 (double precision, 3D version). The CFD package was used to model the solar load on the warehouse as well as the heat dissipation of the PV panel finned heat pipe cooling system. The macroclimate contains the free-stream boundary conditions.

B. Pre-Proccessing

The models of the Warehouse project and the Finned heat pipe arrangement were created using Solid-Edge ST modeling software. The models were then imported into GAMBIT (FLUENT pre-processor), where an additional geometry, a macroclimate was created for both the warehouse and finned heat pipe.

C. Model Set-Up

Meshes for both the models were created in GAMBIT. The mesh details are shown below in tables 2 and 3.

Table II Mesh report for the warehouse

Domain	Nodes	Elements
Macroclimate	112966	604436
Warehouse	16833	85168
All domain	129799	689604

TABLE III MESH REPORT FOR THE FINNED HEAT PIPE ARRANGEMENT

Domain	Nodes	Elements
Copper-pipe	2607	7735
Fins	14026	37311
Macroclimate	53631	235741
Saddle	1734	6731
Solar panel	34819	165588
Working fluid	1224	4328
All domain	108041	457434

A 3D geometry with specific grids near the walls was provided for modeling of wind velocity, solar load on the warehouse and heat transfer within the heat pipe and fins. Figs. 13 and 14 show the geometry and created grids on them.

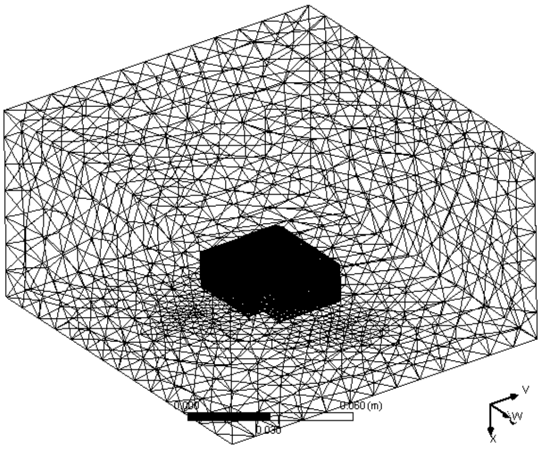


Fig. 13: Meshed model of the warehouse

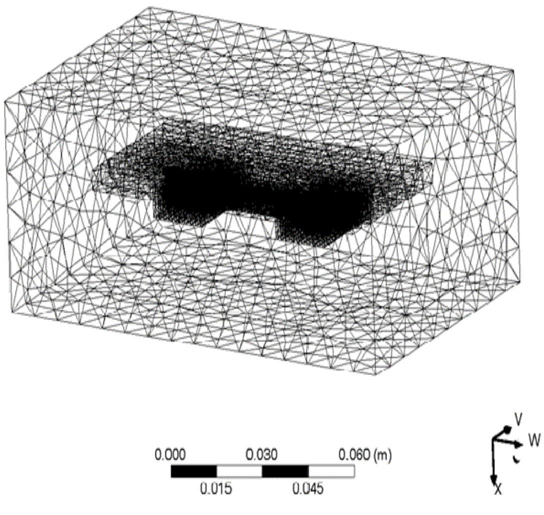


Fig. 14: Meshed model of the heat pipe arrangement with the solar panel

A. Boundary Conditions

After the mesh generation, boundary conditions for the inlet and outlet were set using FLUENT. The flow is natural ventilation and thus expected to be of low turbulence, so a standard k-epsilon turbulence model was enabled. A value of -9.81m/s was specified for the effect of gravity, inlet is set as velocity inlet (value of 4.2m/s) in the direction of positive y-axis outlet set as pressure outlet on the opposite side of the microclimate of both the models. The material properties for both the models are enlisted below in table 4 and the dimensions of the various components are in table 5.

TABLE IV MATERIAL PROPERTIES FOR THE MODELS

Materials	**Density**	**Cp(Specific Heat) j/kgK**	**Thermal Conductivity w/mK**
Warehouse			
Macroclimate (Atmosphere)	1.225	1006.43	0.0242
Eco-Block (Walls)	25.6	1400	0.035
Concrete (Floors)	2300	1000	1.63
Glass (Windows)	2500	840	1.92
Aluminum	2719	871	202.4
Finned Heat Pipe			
Sir (PV Panel)	5910	371	406
Copper-Pipe	8978	381	387.6
Aluminum (Frame of PV panel and fins)	2719	871	202.4

TABLE V DIMENSIONS OF THE GEOMETRY

	Dimensions	Material
Warehouse		
Wall-Thickness	0.25m	Insulated or Insulating Concrete Forms (ICFs)
Roof	40.6m x 35.3m x 14.01m x 0.25m(Thickness)	Aluminum
Floor	40.6m x 35.3m x 0.9m(Thickness)	Concrete
Finned Heat Pipe		
Saddle	6.6cm x 6.6cm x 2.2cm	Aluminum
Heat Pipe	2cm(Diameter) x 30.5cm(Length), 1cm (Wall-thickness)	Copper/Water
Fin	10cm x 5cm x 0.1cm (thickness)	Aluminum

VIII. Results

A. Cell Temperature

As per Solarnova's Photovoltaic Module SOL GT (mono-crystalline PV) datasheet, the NOCT for the module is 44.8^{0}C [20]. Using the Ross, R.G. (1980)[20] approximation to calculate the cell temperature (T_{cell}).

TABLE VI Ross Approximation for Cell Temperature

Month	T air (^{0}C)	S (W/m^2)	T cell (^{0}C)
Jan	24	450	37.95
Feb	25	425	38.175
Mar	28	475	42.725
Apr	32	500	47.5
May	37	500	52.5
Jun	39	400	51.4
Jul	41	375	52.625
Aug	41	350	51.85
Sep	39	500	54.5
Oct	35	500	50.5
Nov	30	450	43.95
Dec	26	350	36.85

The climatic conditions in the UAE lead to the corresponding cell temperatures given by the Ross, R.G. (1980) approximation.

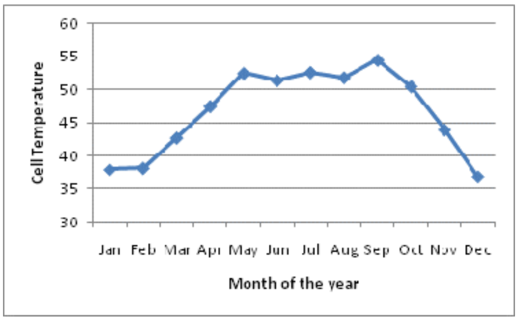


Fig. 15: Cell Temperatures at different times of the year

B. Warehouse Simulation

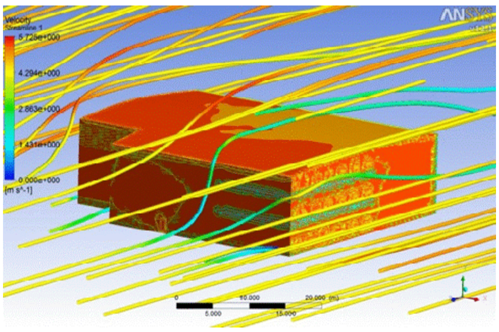


Fig. 16: Air flow on the warehouse and surface temperatures

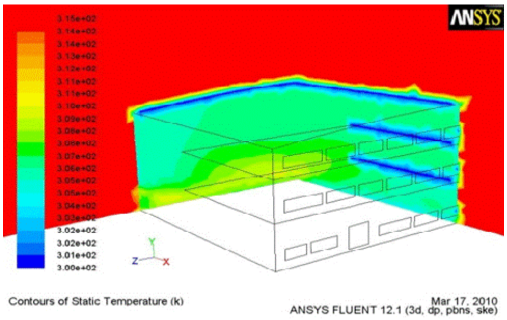


Fig. 17: Temperature Contours inside the warehouse

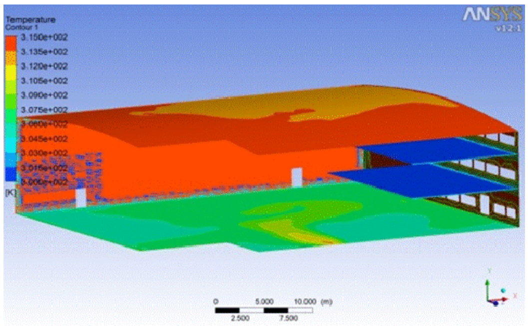


Fig. 18: Surface temperatures of the warehouse

C. Finned Heat Pipe Stimulation

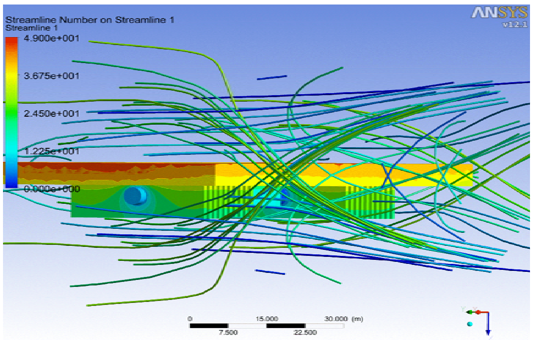
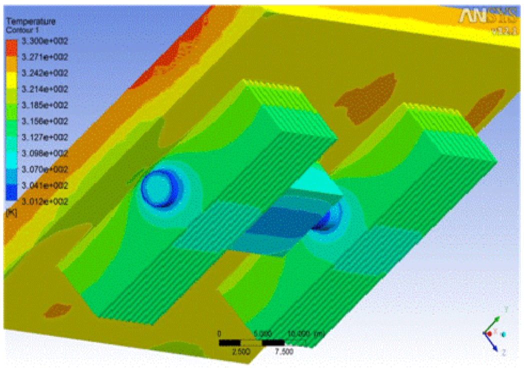


Fig. 19: Air flow on the arrangement and the surface temperatures



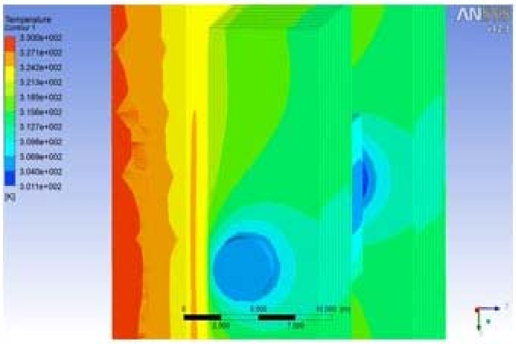


Fig. 20: Surface temperatures on the arrangement

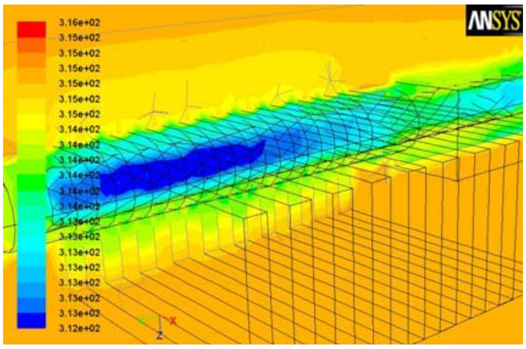


Fig. 21: Heat Transfer through the arrangement at 300 iterations of FLUENT

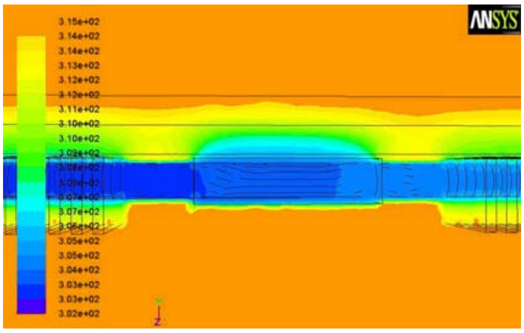


Fig. 22: Heat Transfer through the arrangement at 2000 iterations of FLUENT

TABLE VII TABLE SUMMARIZING THE TEMPERATURES ON THE HEAT PIPE ARRANGEMENT

Temperature on panel's surface	Rear of Panel Temperature	Fin Temperature	Heat pipe temperature	Ambient Temperature
318K	338K	305K	293K-318K	315K

D. Weighted Surface Efficiency Calculations

Area of the fins,
A = 20 x 0.05 x 0.1
= $0.1m^2$

Base area in contact with the fins,
A_b = 2 x π x 0.02 x 0.001
= 1.257×10^{-4} m^2

Area of the pipe,
A_p = 2 x π x 0.02 x 0.305
= 0.038 m^2

Non-finned area,
$A_{non\text{-}finned} = A_p - (n \times A_b)$
= $0.038 - (20 \times 1.257 \times 10^{-4})$
= 0.0355 m^2

The weighted surface efficiency (η_w) takes into account the enhancement of a surface due to extend surfaces on a surface. To calculated the weighted efficiency,

$$\dot{Q}_{total} = \dot{Q}_{unfinned} + \dot{Q}_{fin} \tag{2}$$

$$\eta_w A_{total} \alpha \Delta T_b = A_{unfinned} \alpha \Delta T_b + \eta_{fin} A_{fin} \alpha \Delta T_b$$

$$\Rightarrow \eta_w = \frac{A_{unfinned} + \eta_{fin} A_{fin}}{A_{total}} \tag{3}$$

since the fins are designed to be under natural convection,

$$\eta_{fin} = \frac{\tanh ml + \frac{\alpha}{mk}}{\left[1 + \frac{\alpha}{mk}\tanh ml\right]\left[\frac{\alpha}{mk} + \tanh ml\right]} \tag{4}$$

where,

$$m = \sqrt{\frac{\alpha P}{k A_b}}$$

$$\alpha = convective\ heat\ transfer,$$

$$P = Perimeter\ of\ contact\ area,$$

$$K = Thermal\ Conductivity,$$

$$\alpha = 8.6 \frac{W}{m^2} \quad for\ aluminium\ and\ air\ interface$$

$$K = 200 \frac{W}{mK} for\ aluminium$$

$$P = ((2\pi 0.02) + 0.001) \times 20 = 2.533\ m$$

Hence,

$$m = 29.42 m^{-1}$$
$$\eta_{fin} = 0.99$$

The weighted surface efficiency can hence be calculated,

$$\eta_w = 33.5\%$$

IX. Discussions

Table 6, shows the cell temperature for a standard solar cell vs. month in a year in Dubai. This is illustrated with the help of cell temperature calculations shown in section 3.1 with the UAE climatic conditions shown in Fig. 15. It is evident that for half the year the cell temperature is greater than the NOCT. Also the average temperatures have been considered for the calculations. The temperature of the ambient air temperature may reach as high as 45-50^{0}C in the summer ($T_{cell} \approx 60^0$C), which requires cooling.

Figs. 16, 17 and 18 depicts the CFD analysis results achieved from the solar load model of the warehouse. The figures also show the overall heat transfer coefficient predicted by the CFD code obtained with the input parameters previously described (tables 4 and 5). Global position of the UAE is longitude and latitude of 25°18’N, 55°20’E, respectively. The average density of air and properties of the materials in the warehouse are shown in tables 2 and 3.

Fig. 16 demonstrates the velocity contours around the warehouse with the average wind speed in the UAE of 4.2m/s. Temperature contours of the warehouse are displayed in figs. 17 (across the X and Z plane) and fig. 18 (the inner walls), where the color difference corresponds to different temperatures. As observed, the main colors are red, green and blue temperature contours representing the hottest region to the coolest region, respectively. The legend portrays temperature and color gradient in the range of 290K (blue) – 320K (red). The temperature profile of the heat transfer marked in different colors demonstrated in the figures concludes the roof’s temperature to be 318K, surrounding temperature to be 315K and interior temperature in the range of 290K – 300K.

The results of the analysis of the CFD simulation are used to achieve accurate heat transfer of the finned heat pipe arrangement. The amount of solar intensity on the roof was incorporated into the CFD analysis for the finned heat pipe arrangement on a standard PV panel.

In fig. 19, the free-stream airflow over the finned heat pipe arrangement is displayed with input values from tables 4 and 5, and the wind speed of 4.2m/s using post-processing.

Fig. 20 reveals the temperature contours on the surfaces of the proposed finned heat pipe arrangement when the solution converged in FLUENT. In which, the measured wall’s temperature namely, the rear side of the PV panel, is 338K. The heat pipe temperature range of 293-318K and the fins temperature of 305K are illustrated and are summarized in table 7. It is then observed that with the help of the finned heat pipe arrangement and natural convection (wind speed of 4.2m/s and temperature of 315K) the PV panel has an operating temperature on the solar cells of 300K.

Iteration intervals generated when solving calculations using FLUENT are displayed in figs. 21 and 22; it can be observed that heat from the rear side of the PV panel is being absorbed by the saddle, which is the heat sink, followed by the heat pipe and to the fins. The idea of the heat pipe is that the cold working fluid evaporates the heat from the saddle, turning hot vapor and flows along the heat pipe transferring heat to the fins. Condensation then occurs at the fins by natural convection (atmosphere) described earlier in section 5.4 fig. 6, where the hot working fluid cools, therefore creating a circular motion in the heat pipe.

Fig. 21 taken at 300 iterations shows the proposed finned heat pipe absorbing heat from the saddle, and fig. 22 demonstrated at 3000 iterations, the finned heat pipe starts to cool the PV panel as desired. Comparing the two figures, the heat absorption at the saddle in fig. 21 starts to cool in fig. 22 represented by color regions turning from yellow, green to blue. Within the heat pipe, the green regions over more iterations turns blue representing cooling by natural convection with the help of fins. The CFD analysis results successfully demonstrated the feasibility of the proposed finned heat pipe arrangement cooling solution for PV panels.

A comparison between CFD predicted and measured temperature profile with mathematical calculations, shown in section 8.4, was observed. A reasonable agreement can be observed that the use of fins on heat pipe is more efficient as compared to heat pipes alone. Also, that cooling of PV panels to its maximum operating efficiency by maintaining the solar cell operating temperature under the UAE’s climatic conditions can be obtained with the help of the proposed finned heat pipe arrangement.

X. Conclusion

This study confirms the advantages of a finned heat pipe for practical use, especially in the high-temperature region. The temperature of the PV panel for power generation systems set up on a roof may exceed 70^0 C and by using the proposed finned heat pipe arrangement; by reducing the free-stream temperature back to within the range of the operating temperature of a solar cell, its higher output power thus achieved.

The proposed finned heat pipe can be used to passively remove the heat, accepting high heat flux by natural convection, at a much lower heat flux. A copper heat pipe with water as the working fluid and fins attached was examined by a series of CFD analyses. The CFD analyses determined the optimum temperature cooled under the UAE environmental conditions, which is in the range of solar cells operating temperature of 30^0 C.

It encourages continuing investigations in this direction, with the final goal to create a cooling system to maintaining the cell temperature within the operating temperature of the PV module and to generate both thermal and electrical energy simultaneously by using the proposed finned heat pipe arrangement. To achieve this, SPC coils have provided a prototype heat pipe shown in section, based on this current study for future testing here in Dubai.

Acknowledgement

This project was sponsored by Heriot-Watt University, Dubai Campus., special thanks to Mr Richard Meskimmon (technical manager) of SPC coils ltd, Emirates Green Building Council (EGBC) and Royal City Contracting for the case study, and fabrication of the heat pipe.

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