Experimental Validation of 1D model for photovoltaic/ thermal (PV/T) modules

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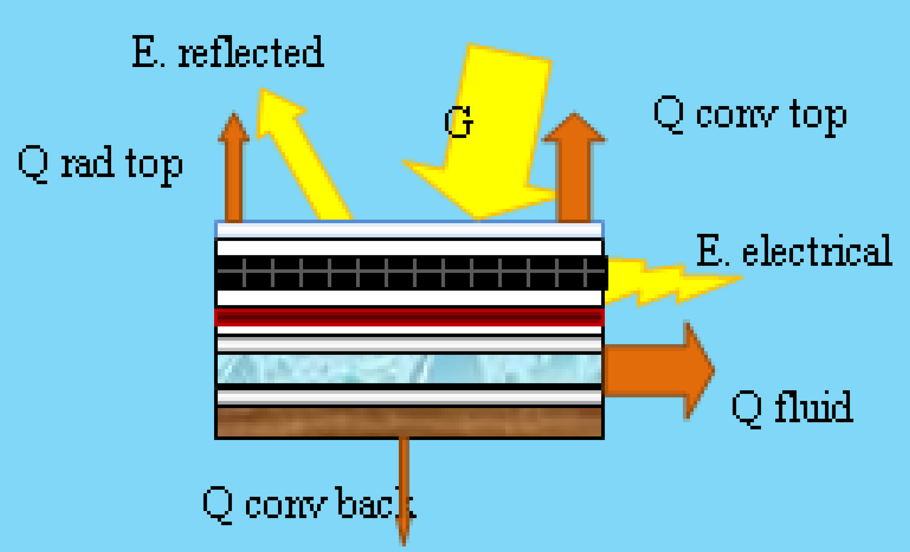
Numerical PV/T model

An energy balance for a quasi 1D simplified model



$$\begin{cases} \underbrace{(\tau_\alpha).G.\left(1-\eta_{PV}(G.T_{PV})\right)}_{\text{Solar Recovered energy}} = \underbrace{h_{RAD}(T_{PV}).(T_{PV}(x)-T_{SKY})}_{\text{Radiative exchange with ambiant}} \\ + \underbrace{H_{TOP}(V_{WIND}).(T_{PV}(x)-T_A)}_{\text{Convective exchange with external}} + \underbrace{H_{FLUID}.(T_{PV}(x)-T_F(x))}_{\text{Convective exchange with the water}} \quad (eq.1) \\ H_{FLUID}.(T_{PV}(x)-T_F(x)) = H_{BACK}.(T_F(x)-T_{BACK}) + \dot{m}.Cp.\frac{dT_F}{dx} \quad (eq.2) \end{cases}$$

Module outlet temperature and electrical power are then deduced thanks to an iterative approach on photovoltaic temperature (T_{PV}).

$$T_{F.OUT} = (T_{F.IN} - C) \times e^{-D.Width} + C \qquad \text{(eq. 3)}$$
$$T_{PV} = A \times T_{F.MEAN} + B \qquad \text{(eq. 4)}$$

Symbol	Meaning	Units
A. B. C and D	Coefficients depending on module characteristics	
Cp	Heat capacity	W/kg/K
G	Solar irradiation	W/m²
H	Global coefficient	W/m²/K
h_{RAD}	Radiative coefficient	W/m²/K
H_{WIND}	Convective coefficient on top plate due to the wind	W/m²/K
H_{FLUID}	Convective coefficient on the plate due to the water	W/m²/K
$\dot{m}$	Water Flow rate	L/s
T	Temperature	K
V_{WIND}	Wind velocity	m/s
Width	Width of solar collector	m
X	Water flow direction	
t_α	Transmitto-absorption on diffuse. direct and horizontal irradiation	-
η_{PV}	Electrical efficiency	-
η_{TH}	Thermal efficiency	-

Subscript	Meaning
A	Ambient
BACK	Between fluid and rear surface
F	Fluid
FLUID	Between PV cells and fluid
PV	Photovoltaic cells
TOP	Between cells and ambient

In non-null flow rate cases. equations were simplified (Solar Keymark standard directives)

$$\eta_{TH} = a_0 - a_1 \times \left(\frac{T_{F.MEAN} - T_A}{G}\right) \qquad \text{(eq. 5)}$$

Relations between the 1D-model and the linear formula

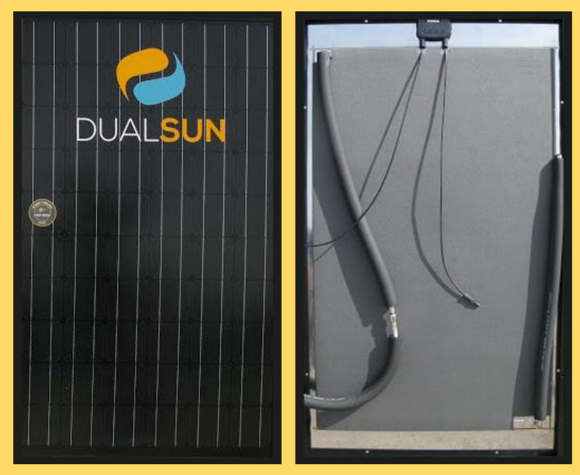
$$a_0 = \frac{\dot{m}\cdot Cp\cdot D\cdot Width\cdot(C - T_A)}{G\cdot Area} \qquad \text{(eq. 6)}$$

$$a_1 = \frac{\dot{m}\cdot Cp\cdot D\cdot Width}{Area} \qquad \text{(eq. 7)}$$

Prototypes and testing

Description of the constitutive layers for the 9 prototypes tested

	Glass	EVA	Cells	EVA	BS	EVA	Stainless Steel Heat exchanger / PV surface	Insulation (equivalent thickness given for k=0.033W/(m.K))
	mm	mm	-	mm	mm	mm	-	mm_equiv
1	2	0.6	60 (MPPT)	1.2	0.4	1.2	74%	NO
2	2	0.6	60 (OC)	1.2	0.4	1.2	74%	NO
3	2	0.6	60 (MPPT)	1.2	0.4	1.2	74%	39.6mm
4	2	0.6	60 (MPPT)	1.2	0.4	1.2	74%	24.8mm
5	2	0.6	60 (MPPT)	0.6	0.4	0.6	74%	NO
6	4 & Low E	0.6	60 (MPPT)	1.2	0.4	1.2	74%	NO
7	2	-	-	0.6	0.4	0.6	74%	NO
8	-	-	-	-	-	-	exch only	NO
9	2	0.6	40 (OC)	1.2	0.4	1.2	100%	NO



*Ex of prototype (1669*982mm²)*

Pictures of the artificial sunlight test bench (1000W/m². wind speed 1.5m/s. $T_{F.in}$=20..70°C)

Photovoltaic and thermal results for the 9 prototypes

	a0 (%)	a1 (W/K/m²)	Wp *	β_{Wp} (%/°C)
1	50.2%	12.8	238	-0.048
2	59.9%	13.1	-	-
3	49.6%	10.6	238	-0.050
4	49.8%	11.4	238	-0.050
5	52.8%	13.1	245	-0.055
6	49.8%	13.0	225	-0.050
7	66.1%	13.3	-	-
8	39.8%	11.3	-	-
9	75.7%	17.9	-	-

*limiting cell equivalent power at 1000W/m² and 25°C

Model validation

Introduction of two new factors in the model

Two parameters were introduced to take better into account for the specific behavior of the Dualsun stainless steel heat exchanger :

- Effect of the fin

⇒ Correction of the ratio Stainless Steel Heat exchanger / PV surface
82% instead of 74%

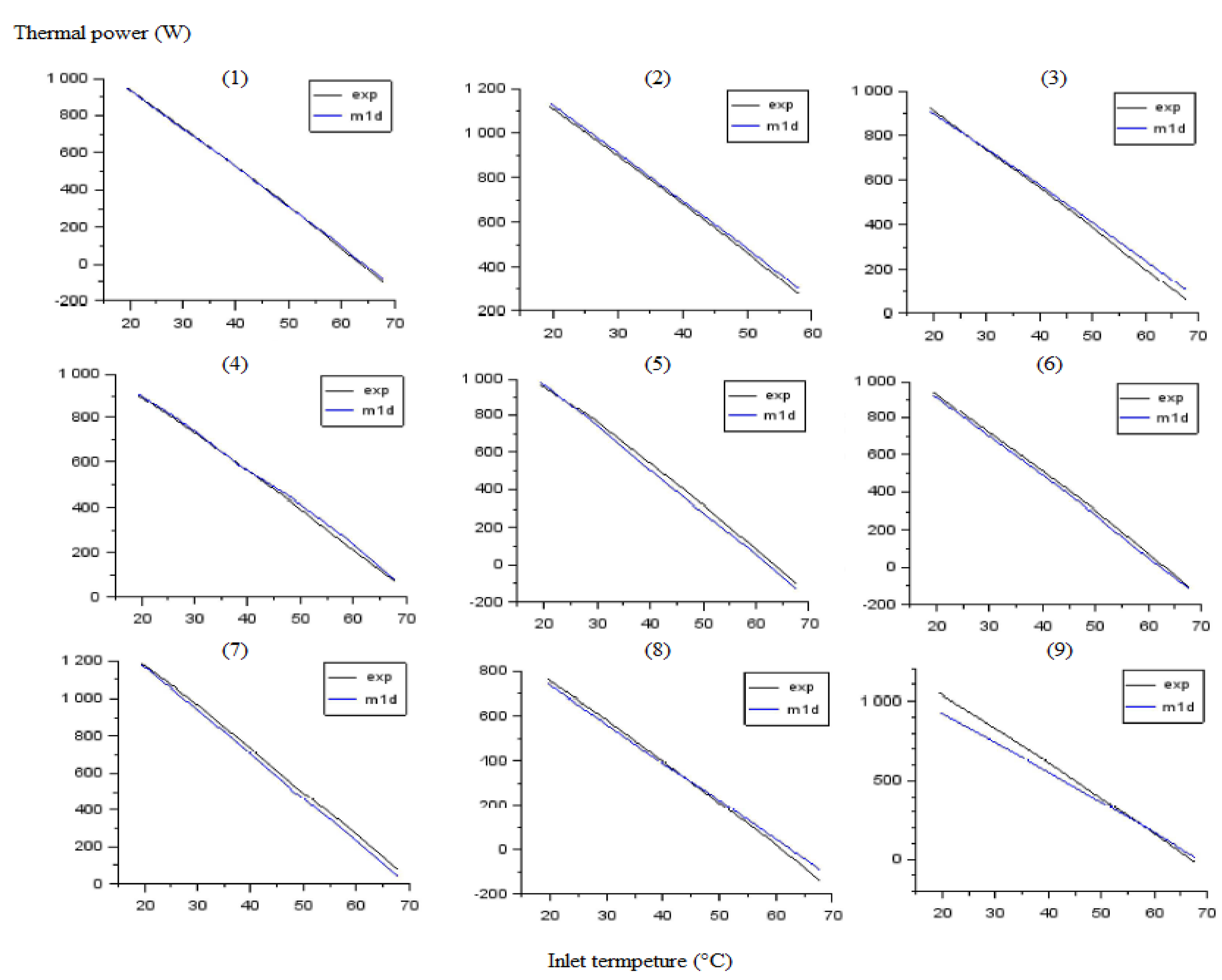
- Unknown heat exchange between the fluid and the stainless steel (which was supposed fixed at 800 W/(m².K))

⇒ Correction of the length of exchange
770mm instead of 856mm

Root-mean-square error for each model/ test fitting with the corrected model

Test	1	2	3	4	5	6	7	8	9
RMSE	8.74	17.14	26.39	15.09	29.98	20.33	28.35	25.42	66.98

Visualization of model and experimental results



The simplified model (1D) gives a good fit with the 9 first prototypes performance results.
These encouraging results must be confirmed with further tests with a polymeric heat exchanger.