Thermal Loss Analysis For A Standalone PV Power Installation

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Abstract— **In this paper, simulated thermal loss analysis for a standalone photovoltaic (PV) power installation for a microfinance bank is presented. The study considered four different thermal loss factor setups, namely; Case I; semi-integrated PV module with air duct behind with thermal loss factors, Uo = 20 and U1 = 0; Case II: free-standing PV arrays which is the current PVSyst default with thermal loss factors, Uo =29 and U1 = 0; Case III: Integrated PV module with fully insulated back which is the setting for a close roof mounted fully insulated PV arrays with thermal loss factors, Uo =15 and U1 = 0; and Case IV: old version of PVsyst default value with thermal loss factors, Uo =20 and U1 = 6. The PVSyst software was used to conduct the thermal loss analysis of the standalone power system for the four different PV installation setups. Specifically, the cell temperature rise above the ambient temperature, thermal loss due to PV module temperature, PV array efficiency and system efficiency are considered. The results showed that the annual average value of difference between the module temperature and ambient temperature, DTArr (°C) for Case II is the lowest with a value of 37.98°C while that of case III is the highest with a value of 47.49°C. The results for the thermal loss due to temperature, TempLss (kWh) for Case II is the lowest with a value of 364.86 kWh while that of case III is the highest with a value of 623.83 kWh. The results for the PV array efficiency, EffArrR (%) for Case II is the highest with a value of 8.64% while that of case III is the lowest with a value of 7.94%.Furthermore, results for the System Efficiency, EffSysR(%) for Case II is the highest with a value of 8.05 % while that of case III is the lowest with a value of 7.72 % . In all, case II which is for free standing PV installation gave the highest PV array efficiency, highest system efficiency, lowest PV module temperature rise above the ambient temperature and finally the lowest thermal loss. On the other hand, case III which is for integrated PV module installation with fully insulated back and also the setting for close roof mounted PV installation gave the lowest PV array efficiency, lowest system efficiency, highest PV module temperature rise above the ambient temperature and finally the highest thermal loss. The implication is that rooftop PV installation suffers more losses than the free standing PV installation. As such, while space is conserved by re-using the roof for the PV installation, there is a trade-off in the reduction in the PV array efficiency and system efficiency.**

Keywords— Rooftop PV Installation, Thermal Loss Factor, Photovoltaic, Module Temperature, System Efficiency, Ambient Temperature, PV Array Efficiency, Standalone PV Power System

1. INTRODUCTION

Today, photovoltaic (PV) solar power generating system are popularly used in homes and business premised across the globe [1,2,3,4,5,6,7,8,9,10]. Particularly, in the developing countries, PV power generation system (PVPGS) has also become the preferred alternative source of energy to the national grid [11,12,13,14,15,16,17]. This is particularly facilitated by the continual drop in the prices of PVPGS components [18,19,20,21,22].

In any case, over the years, studies have shown that the performance of the PVPGS is affected by the cell temperature which in turn depends on a number of other parameters [23, 24, 25, 26, 27, 28, 29, 30]. Also, the PVSYsyst software that is commonly used to simulate the sizing, operation and performance of PVPGS has its thermal loss factor and PV cell temperature models which can be used to assess the impact of temperature, wind speed and solar radiation on the performance of the PVPGS [31,32]. Consequently, in this paper, a simulated analysis of thermal loss factor setup impact on a standalone PVPGS is presented. The analysis utilized four different thermal loss factor settings in PVSyst software to assess their impact on the cell temperature, the thermal loss due to cell temperature, the PV array efficiency and system efficiency. In all, the ideas presented in this paper will enable PV system designers to select appropriate thermal loss factor in the PVSyst software for their simulation purposes.

2.0 METHODOLOGY

2.1 The case study load demand and meteorological data

The study conducted on a standalone PV power system used to supply electric power to a microfinance bank located in Port Harcourt, Rivers State Nigeria (Figure 1). The thermal loss factor setting impact study on the PV power system utilizes the daily energy demand for the microfinance bank, given in Table 1 and the meteorological data of the case study site, given in Table 2.

Table 1 The daily energy demand data for the Microfinance bank used as case study

Description of Item	Qty	Power (Watts)	Total load (Watts)	Daily Hour of Actual Utilization (hours)	Daily (Wh)
Server (plus accessories)	1	150	150	24	3600
Indoor Lightings	6	40	240	13	3120
HP Deskjet (three-in-one) printer/scanner and photocopier	1	44	44	14	616
ATM Machine	3	1000	3000	24	72000
Premises/Street Lightings	8	50	400	14	5600
Router	1	25	25	24	600
Laptop (with security cable)	1	40	40	24	960
Air conditioners	2	746	1492	14	20888
Wireless Access Point	2	12	24	24	576
TOTAL			**5415**		**107960**

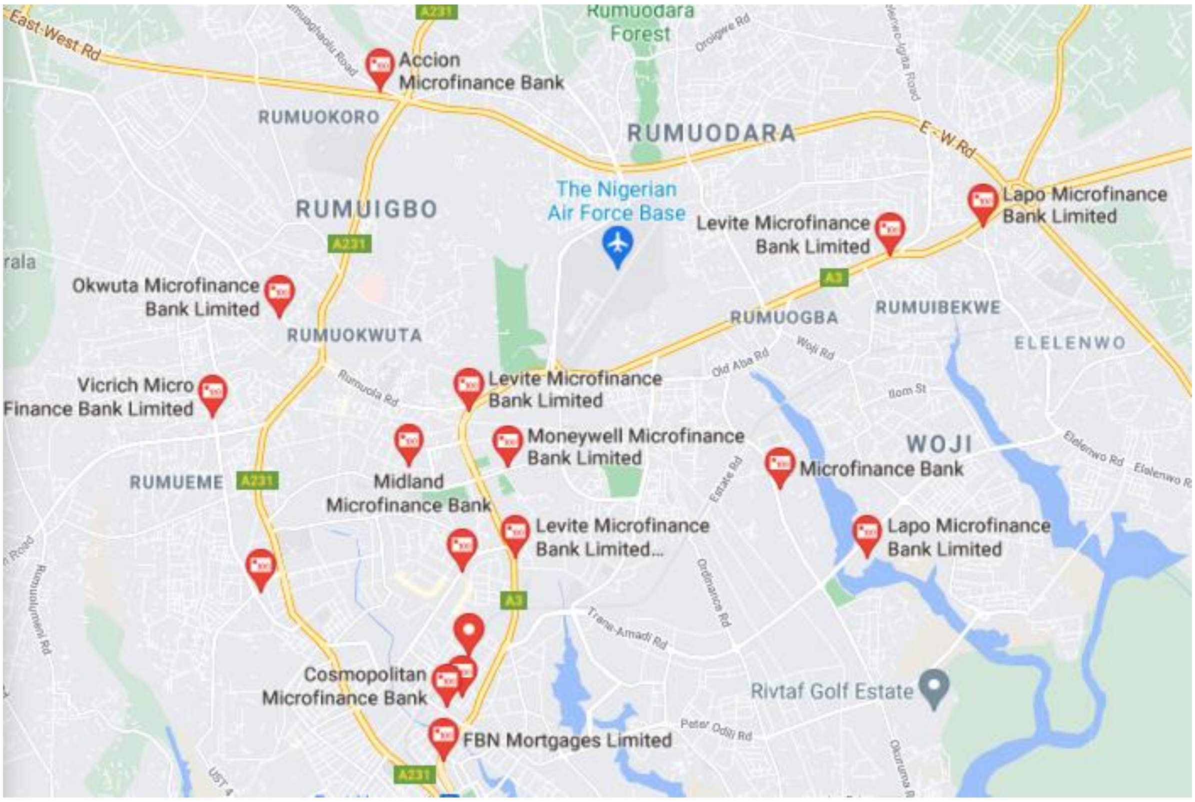
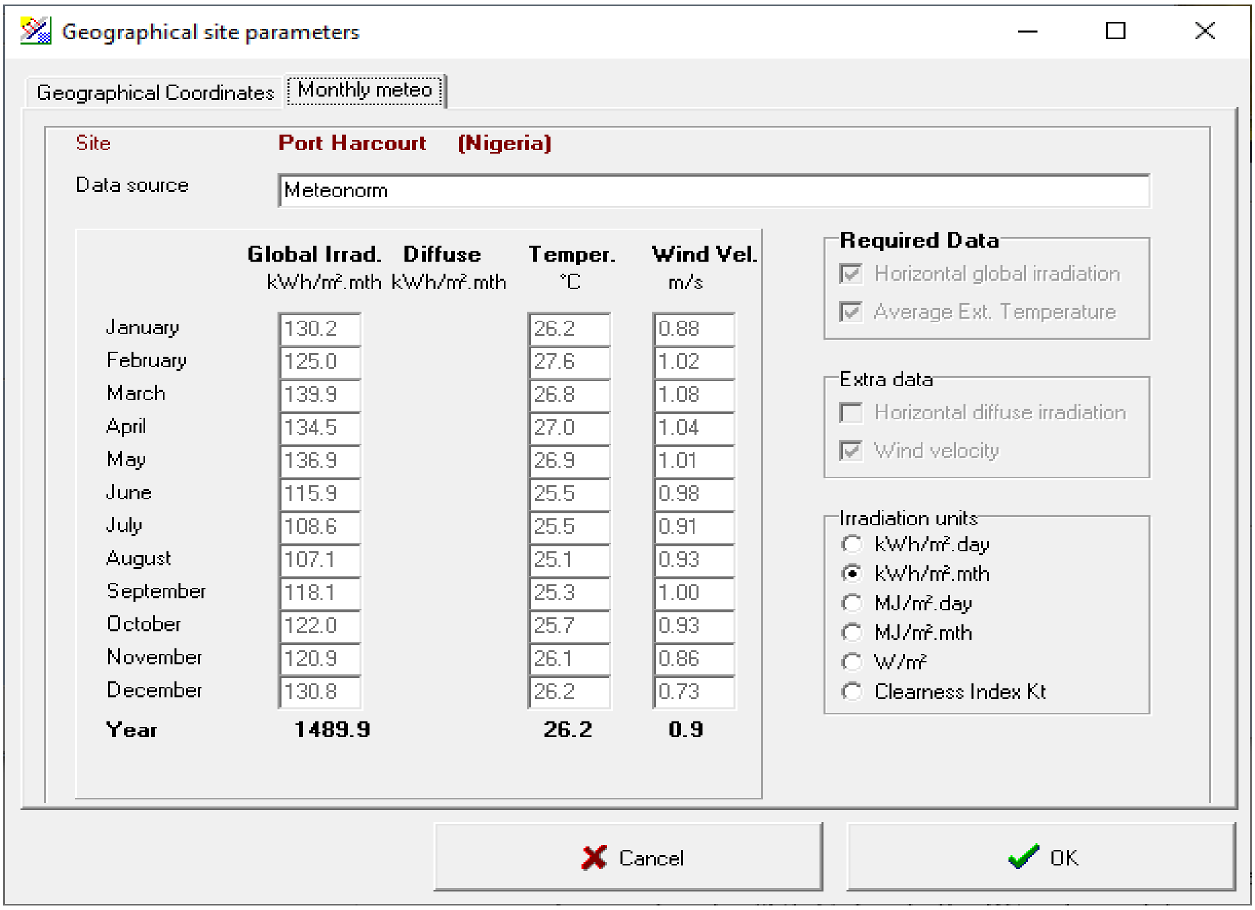


Figure 1 Google Map Plot of some Microfinance Banks in Port Harcourt, Rivers State

Table 2 The meteorological data of the case study site



2.2 The thermal loss factor and cell temperature model in PVSyst

In thermal loss analysis, the single-diode mode is the basis of the thermal loss equation used in PVsyst simulation software while the PV array thermal behavior is based on the energy balance between the cell temperature and the ambient temperature. Let T_{cell} denote the PV array cell temperature (in °C), U denote the PVsyst simulation software thermal loss factor, α denote the solar irradiation absorption coefficient of the PV array, η_{PVSTC} denote the PV array efficiency at Standard Test Condition (STC) and G denotes the irradiance incident on the PV module plane (W/m^2), then, U in PVsyst simulation software is computed as;

$$U\,(T_{cell} - T_a) = \alpha(G)\,(1 - \eta_{PVSTC}) \qquad (1)$$

$$U = \left(\frac{\alpha(G)\,(1 - \eta_{PVSTC})}{T_{cell} - T_a}\right) \qquad (2)$$

Let V_{wind} denote the wind speed in m/s , U_1 denote the convective heat transfer component which is expressed in W/m^2K and U_0 denote the constant heat transfer component expressed in W/m^2K), then the T_{cell} is computed in PVsyst using the Faiman module temperature model, where;

$$T_{cell} = T_a + \left(\frac{\alpha(G)(1-\eta_{PVSTC})}{U_0 + U_1\,(V_{wind})}\right) \qquad (3)$$

The values of U_0 and U_1 are empirically determined, and some available published values for different installation setups are given in Table 3.

Table 3 The values of $\mathbf{U_0}$ and $\mathbf{U_1}$ for different kinds of PV installation setups

S/N	Description	Uo	U1
I	Semi-integrated with air duct behind	20	0
II	Current PVSyst default which is for free-standing arrays	29	0
III	Integrated PV module with fully insulated back , that is close roof mounted fully insulated arrays	15	0
IV	Default value in the old version of PVSyst	20	6

3. RESULTS AND DISCUSSIONS

The PVSyst software is used to conduct the thermal loss analysis for the different four different PV installation setups, as shown in Table 3. Specifically, the cell temperature rise above the ambient temperature, thermal loss due to temperature, PV array efficiency and system efficiency are considered. The components sizing for the battery bank and the PV array are shown in Figure 2.

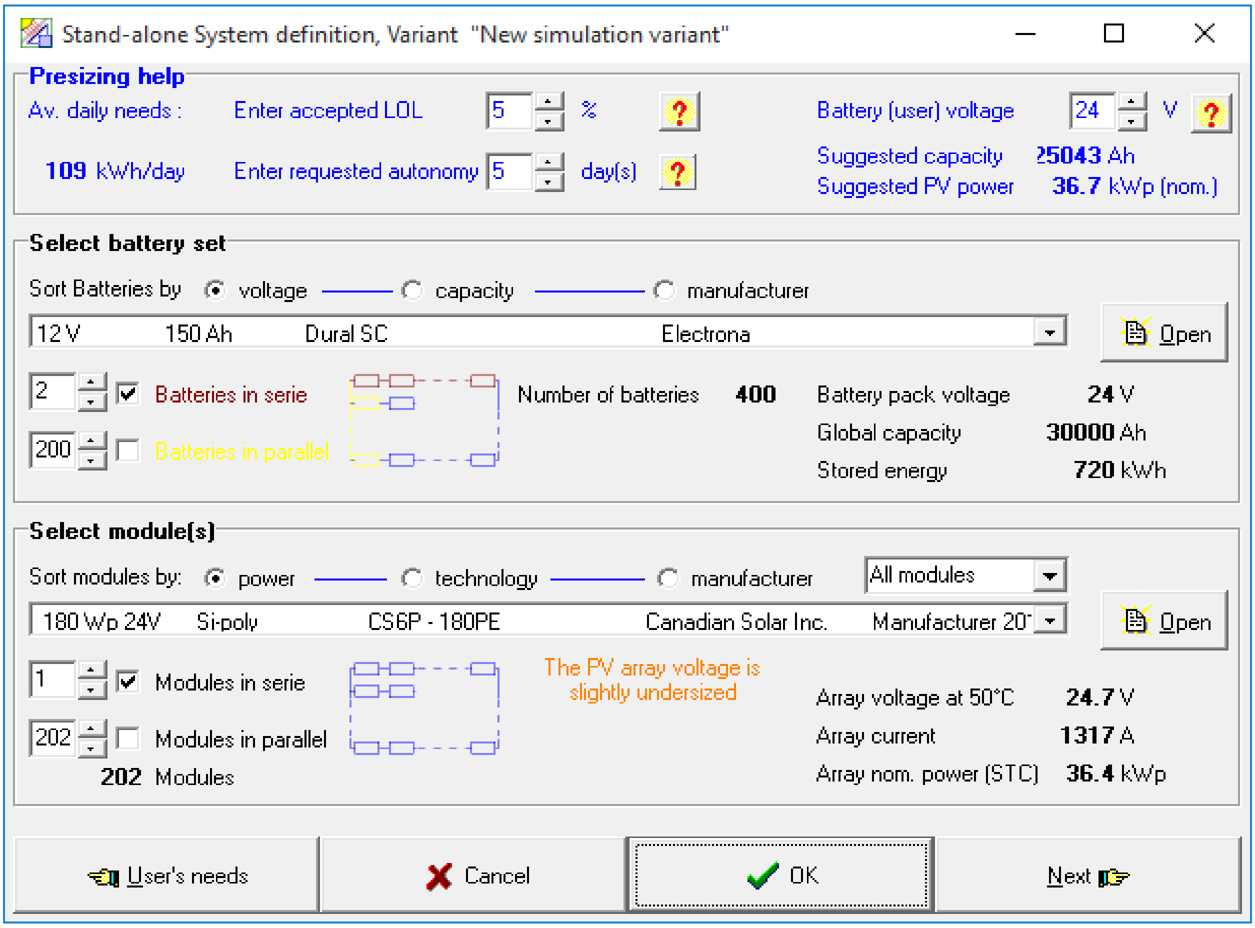


Figure 2 The selected PV array and battery bank for the power system

The thermal loss factor settings and the thermal loss plot for the four different PV installation setups are shown in Figure 3, Figure 4, Figure 5, Figure 6, Figure 7 and Figure 8. The results in Figure 3 and Figure 4 show that for Case I: Uo= Uc= 20 and U1 =Uv=0, the thermal loss is 8.5 % of the PV array annual energy yield.

For Case II: Uo= Uc= 29 and U1 =Uv=0 in Figure 5 and Figure 6, the thermal loss is 7.4 % of the PV array annual energy yield, which is confirmed in the system loss diagram of Figure 8. Again, for Case III: Uo= Uc= 15 and U1 =Uv=0 in Figure 7, the thermal loss is 16.7 % of the PV array annual energy yield, while for Case IV: Uo= Uc= 20 and U1 =Uv=6 in Figure 8, the thermal loss percentage is 8.5 % of the PV array annual energy yield.

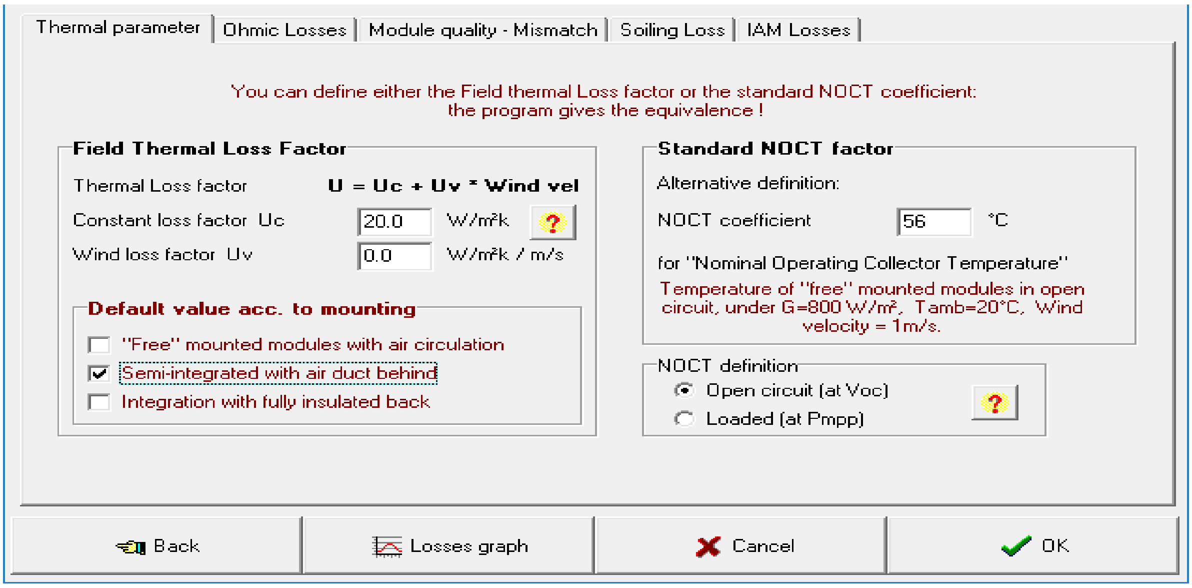


Figure 3 The PVSyst Dialogue Box For Thermal Loss Factor Setting in Case I: Uo= Uc= 20 and U1 =Uv=0

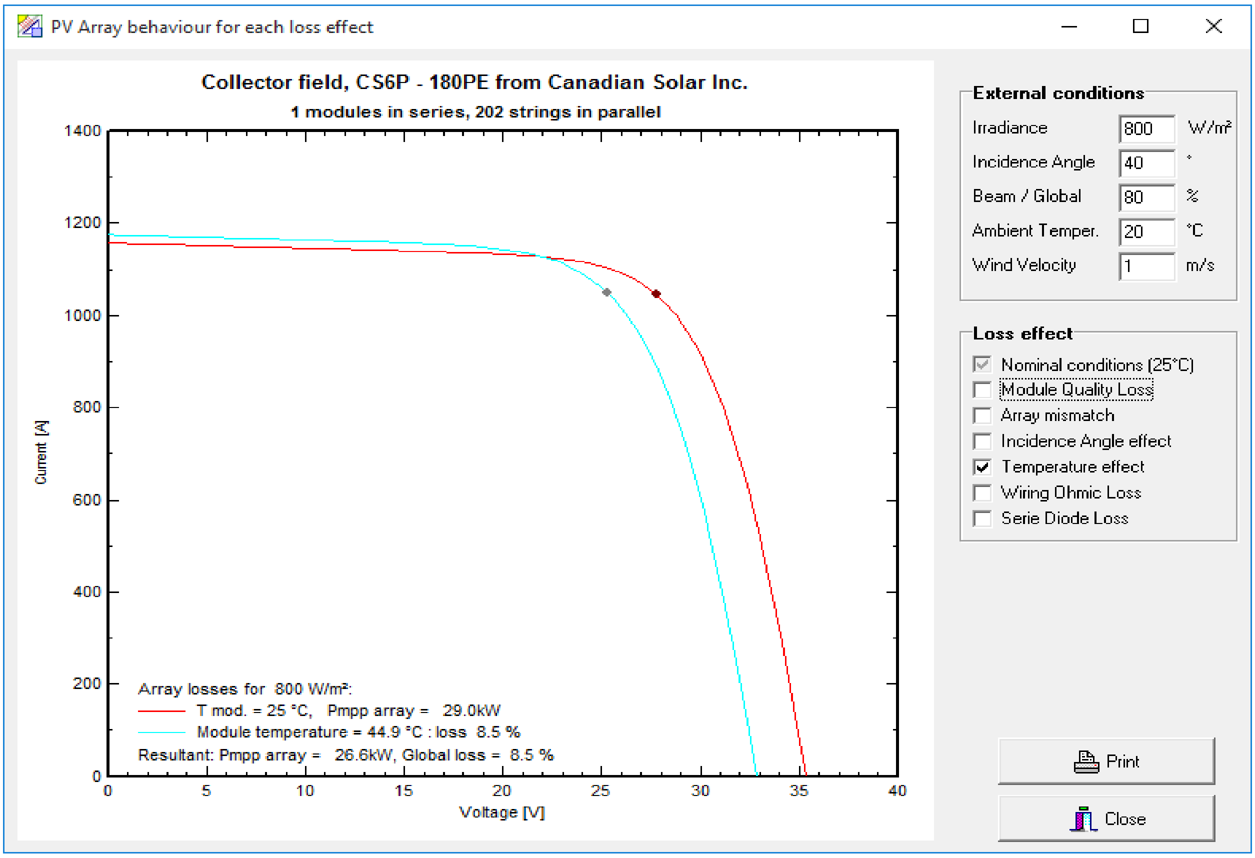


Figure 4 The Thermal Loss Factor (%) for Case I: Uo= Uc= 20 and U1 =Uv=0

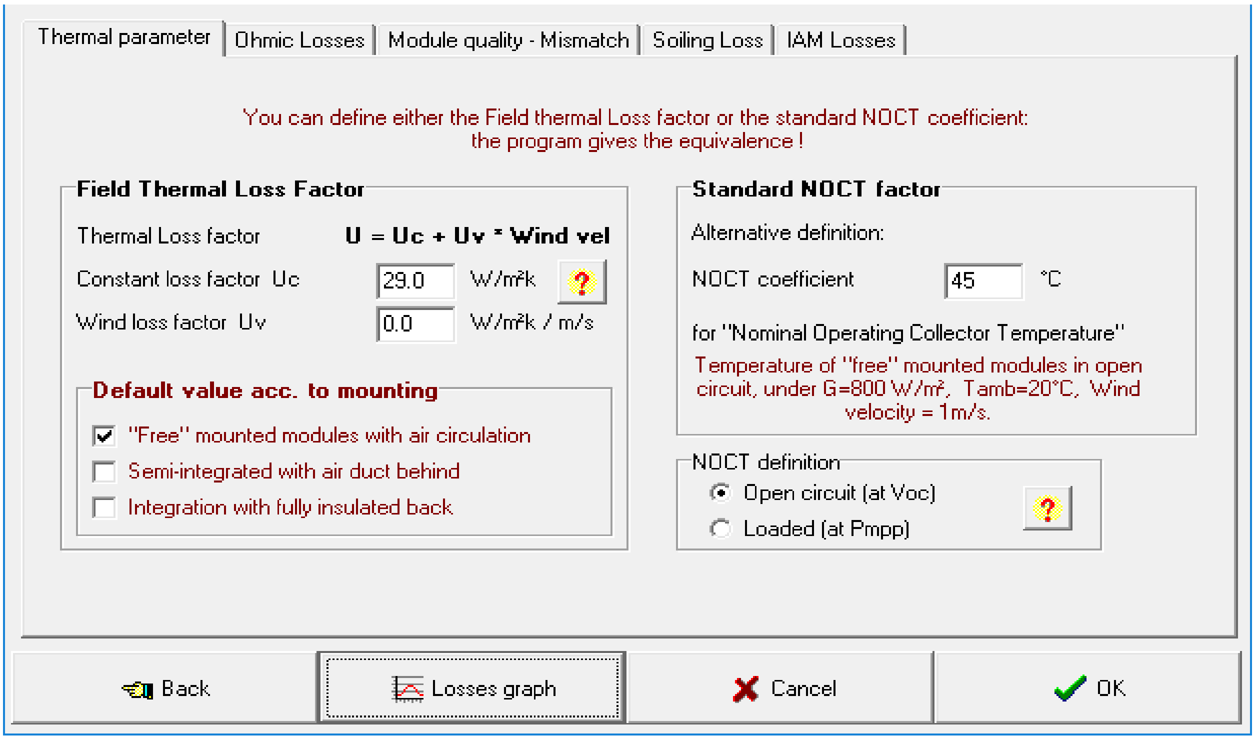


Figure 5 The PVSyst Dialogue Box For Thermal Loss Factor Setting in Case II: Uo= Uc= 29 and U1 =Uv=0

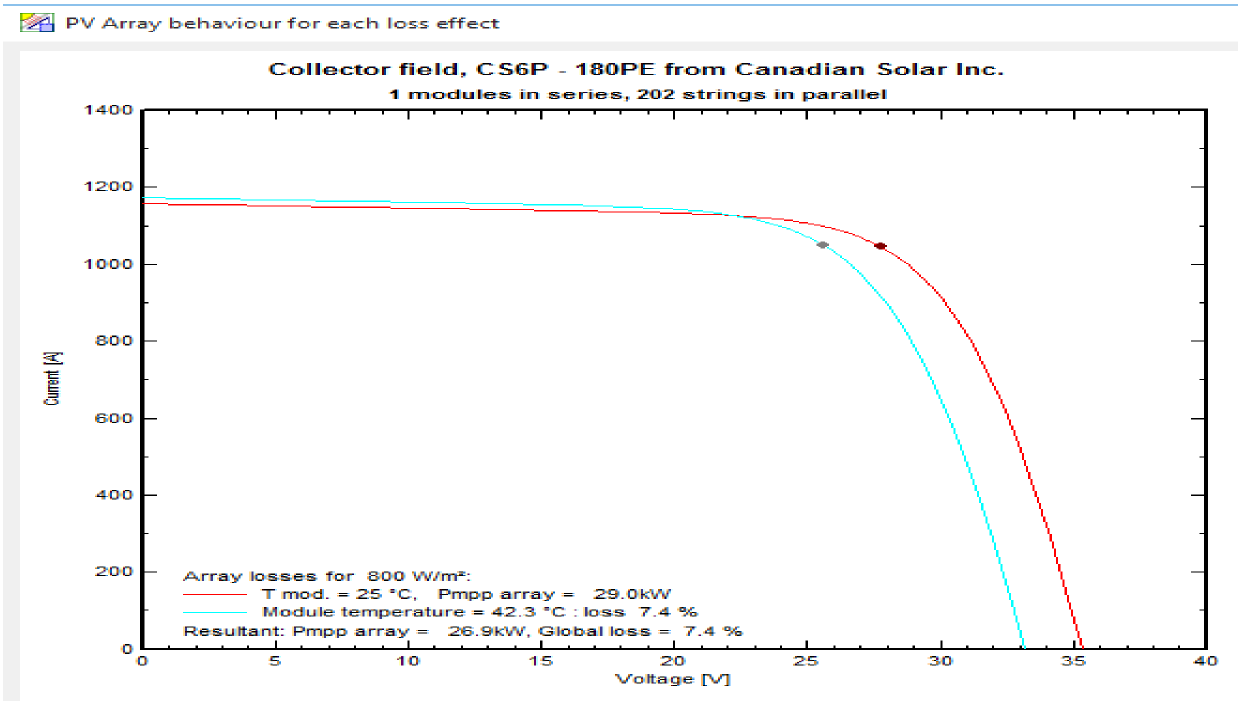


Figure 6 The Thermal Loss Factor (%) for Case II: Uo= Uc= 29 and U1 =Uv=0

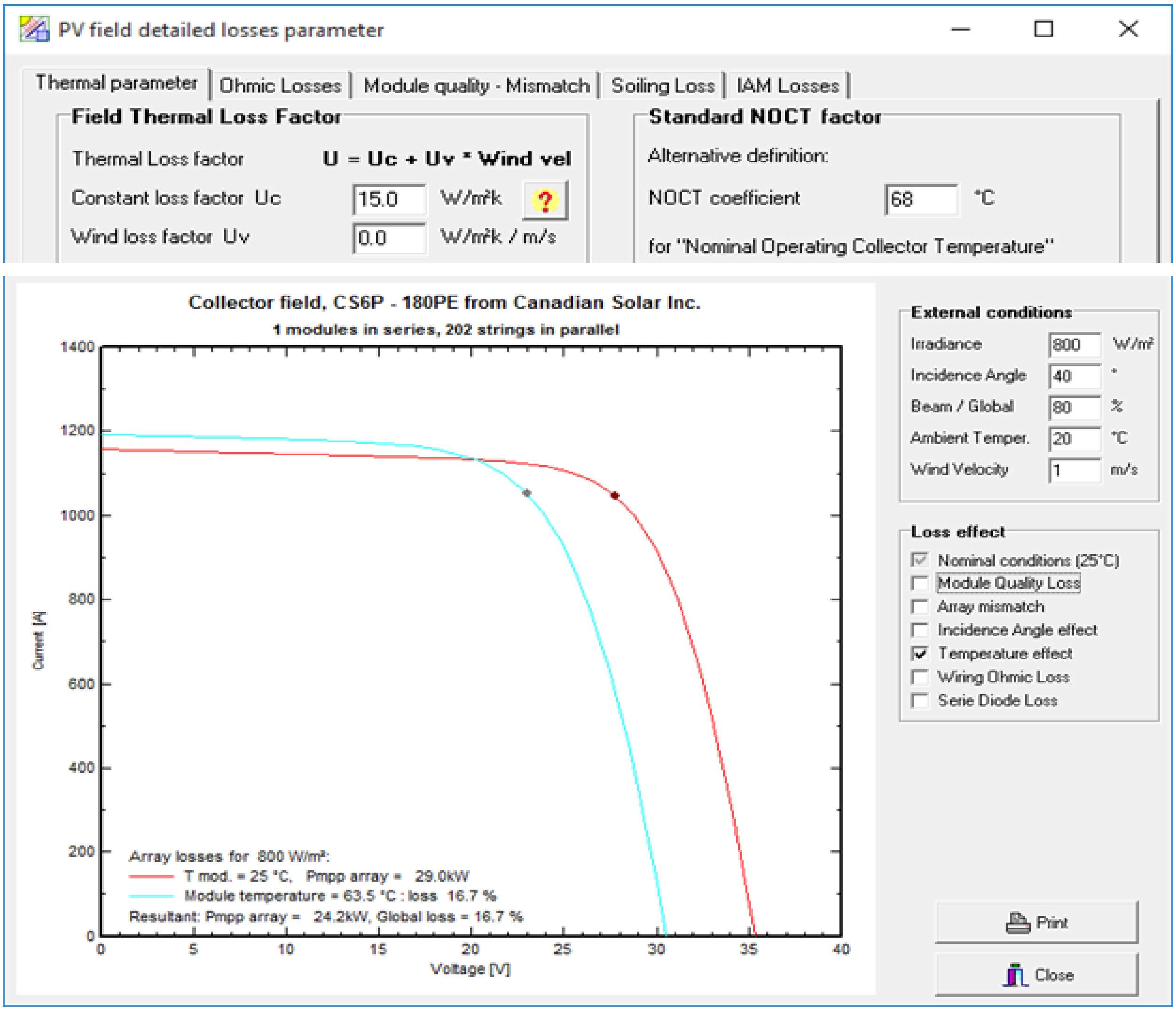


Figure 7 The PVSyst Dialogue Box and Thermal Loss Factor (%) for Case III: Uo= Uc= 15 and U1 =Uv=0

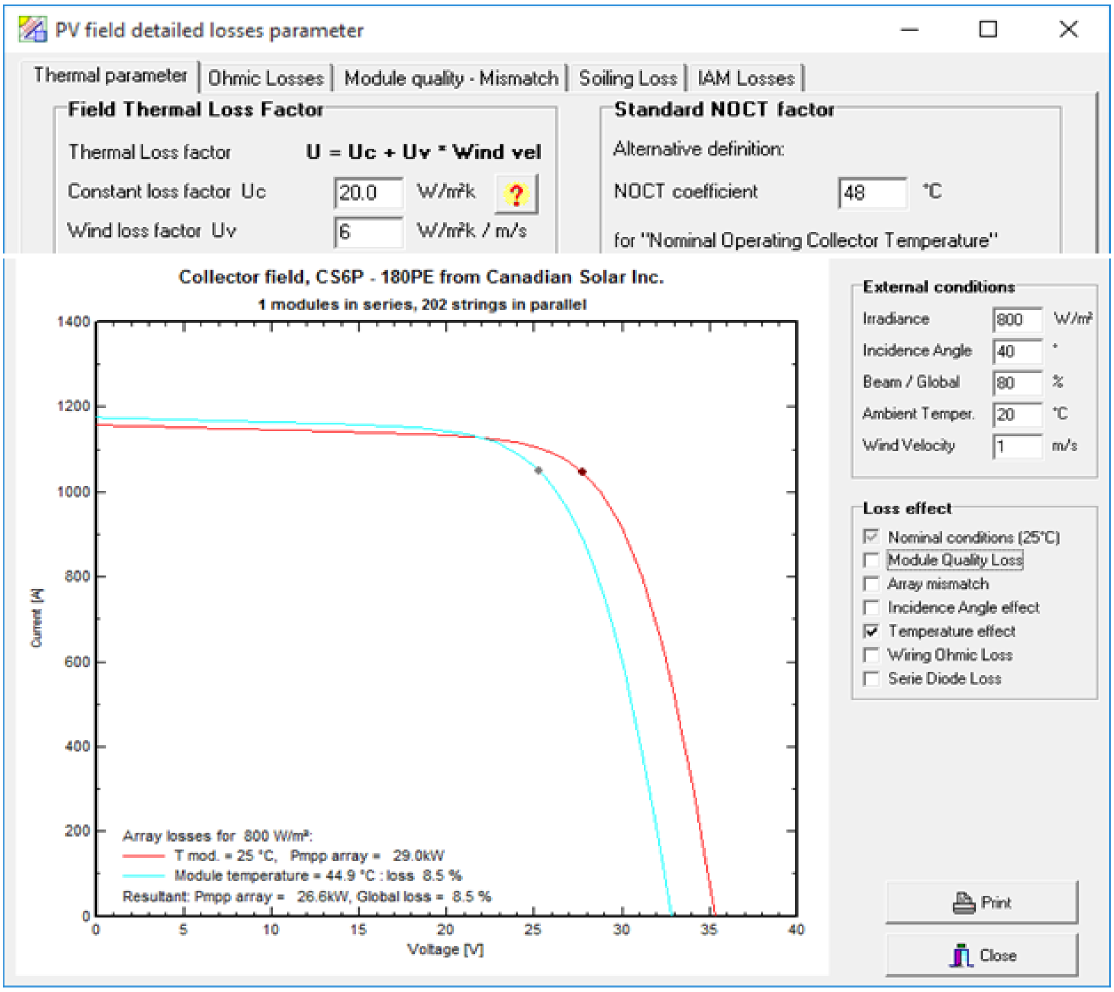


Figure 8 The PVSyst Dialogue Box and Thermal Loss Factor (%) for Case IV: Uo= Uc= 20 and U1 =Uv=6

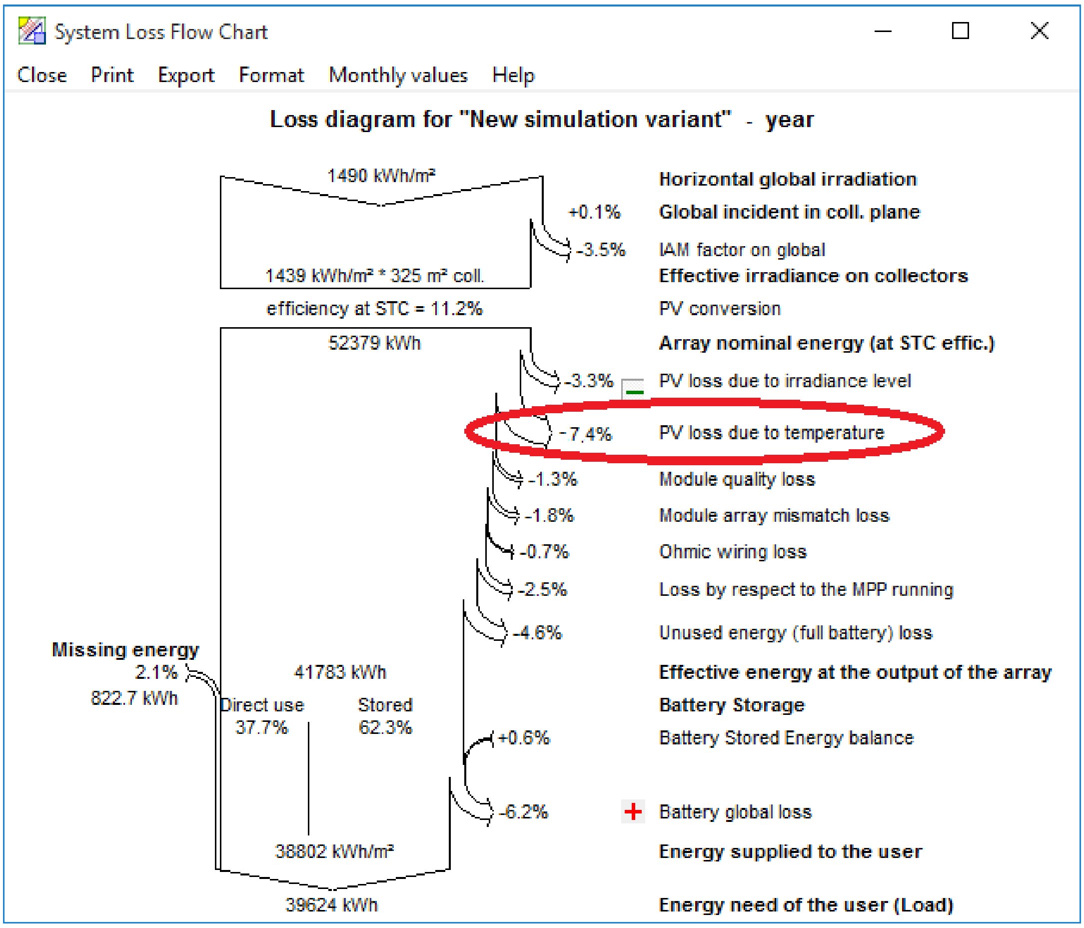


Figure 9 The system loss for Case II: Uo= Uc= 29 and U1 =Uv=0

The results for the difference between the module temperature and ambient temperature, DTArr (°C) for the four different thermal loss factor setups are shown in Table 4 and Figure 10. The results showed that the annual average value of DTArr for Case II is the lowest with a value of 37.98°C while that of case III is the highest with a value of 47.49°C. Also, Case I and Case IV have the same annual average DTArr value of 42.66°C.

Table 4 The difference between the module temperature and ambient temperature, DTArr (°C) for the four different thermal loss factor settings

Month	Month	DTArr (°C) for Case 1 : Uo = 20 and U1 = 0	DTArr (°C) for Case 2 : Uo = 29 and U1 = 0	DTArr (°C) for Case 3 : Uo = 15 and U1 = 0	DTArr (°C) for Case 4 : Uo = 20 and U1 = 6
January	1	44.71	39.91	49.88	44.71
February	2	46.83	41.47	52.1	46.83
March	3	44.45	39.04	49.79	44.45
April	4	44.17	38.6	49.73	44.17
May	5	43.54	38.65	48.5	43.54
June	6	40.25	36.22	44.61	40.25
July	7	38.51	34.9	42.4	38.51
August	8	38.49	34.8	42.46	38.49
September	9	41.11	36.81	45.76	41.11
October	10	41.14	36.88	45.73	41.14
November	11	43.63	38.97	48.5	43.63
December	12	45.07	39.52	50.41	45.07
Year Average		42.66	37.98	47.49	42.66

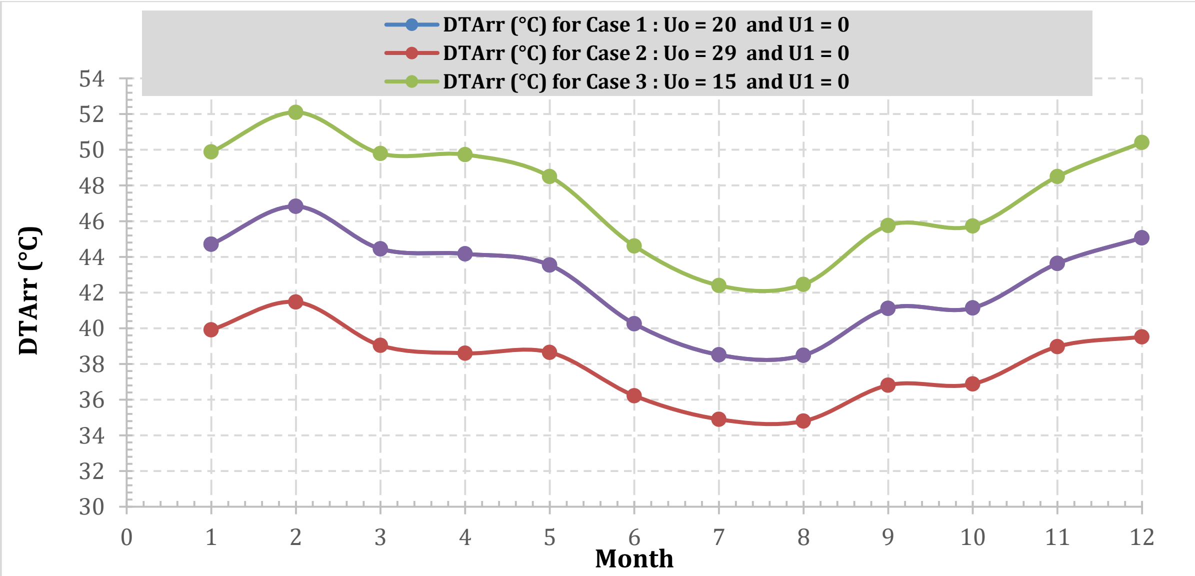


Figure 10 The difference between the module temperature and ambient temperature, DTArr (°C) for the four different thermal loss factor settings

The results for the thermal loss due to temperature, TempLss (kWh) for the four different thermal loss factor setups are shown in Table 5 and FIGURE 11. The results showed that the annual average value of TempLss for Case II is the lowest with a value of 364.86 kWh while that of case III is the highest with a value of 623.83 kWh. Also, Case I and Case IV have the same annual average TempLss value of 488.61 kWh.

Table 5 The thermal loss due to temperature, TempLss (kWh) for the four different thermal loss factor settings

Month	Month	TempLss (kWh) for Case 1 : Uo = 20 and U1 = 0	TempLss (kWh) for Case 2 : Uo = 29 and U1 = 0	TempLss (kWh) for Case 3 : Uo = 15 and U1 = 0	TempLss (kWh) for Case 4 : Uo = 20 and U1 = 6
January	1	556.1	419.5	705.2	556.1
February	2	605.8	466.1	758.4	605.8
March	3	594.6	445.9	757.2	594.6
April	4	545.1	407.3	695.7	545.1
May	5	495.2	368	634.2	495.2
June	6	360.9	264.5	466.2	360.9
July	7	342.9	251.5	442.7	342.9
August	8	358	263.8	460.8	358
September	9	439.7	322.4	567.9	439.7
October	10	473	348.6	608.9	473
November	11	478.4	359	608.9	478.4
December	12	613.6	461.7	779.8	613.6
Year Average	13	488.61	364.86	623.83	488.61

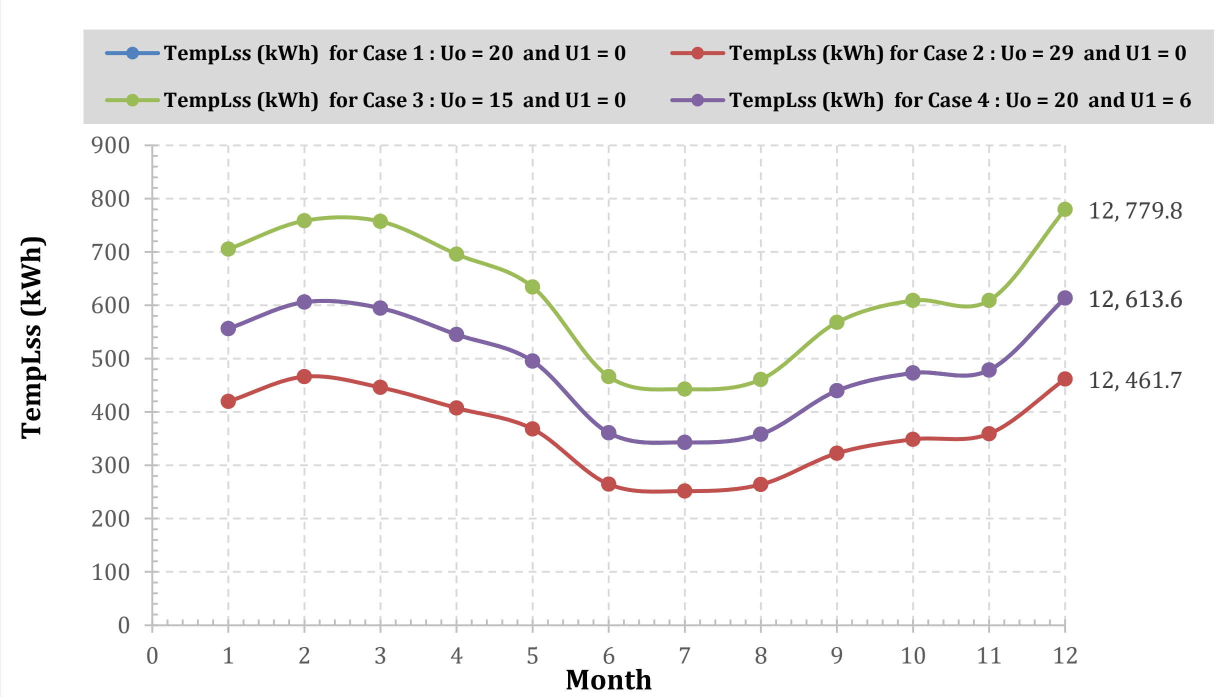


Figure 11 The thermal loss due to temperature, TempLss (kWh) for the four different thermal loss factor settings

The results for the PV array efficiency, EffArrR (%) for the four different thermal loss factor setups are shown in Table 6 and Figure 12. The results showed that the annual average value of EffArrR for Case II is the highest with a value of **8.64**% while that of case III is the lowest with a value of **7.94**% . Also, Case I and Case IV have the same annual average EffArrR value of **8.39**%.

Furthermore, results for the System Efficiency, **EffSysR(%)** for the four different thermal loss factor setups are shown in Table 7 and Figure 13. The results showed that the annual average value of **EffSysR** for Case II is the highest with a value of 8.05 **%** while that of case III is the lowest with a value of 7.72 **%** . Also, Case I and Case IV have the same annual average EffArrR value of 7.97 **%.**

Table 6 The PV array efficiency, EffArrR (%) for the four different thermal loss factor settings

	Month	EffArrR (%) for Case 1 : Uo = 20 and U1 = 0	EffArrR (%) for Case 2 : Uo = 29 and U1 = 0	EffArrR (%) for Case 3 : Uo = 15 and U1 = 0	EffArrR (%) for Case 4 : Uo = 20 and U1 = 6
January	**1**	8.41	8.8	7.77	8.41
February	**2**	7.96	8.15	7.46	7.96
March	**3**	8.01	8.19	7.72	8.01
April	**4**	7.78	7.89	7.7	7.78
May	**5**	8.54	8.64	8.14	8.54
June	**6**	8.71	9.04	8.38	8.71
July	**7**	8.7	9.04	8.27	8.7
August	**8**	8.65	9.01	8.1	8.65
September	**9**	8.66	9.07	8.13	8.66
October	**10**	8.6	8.9	8.15	8.6
November	**11**	8.6	8.77	7.89	8.6
December	**12**	8.11	8.16	7.55	8.11
Year Average		8.39	8.64	7.94	8.39

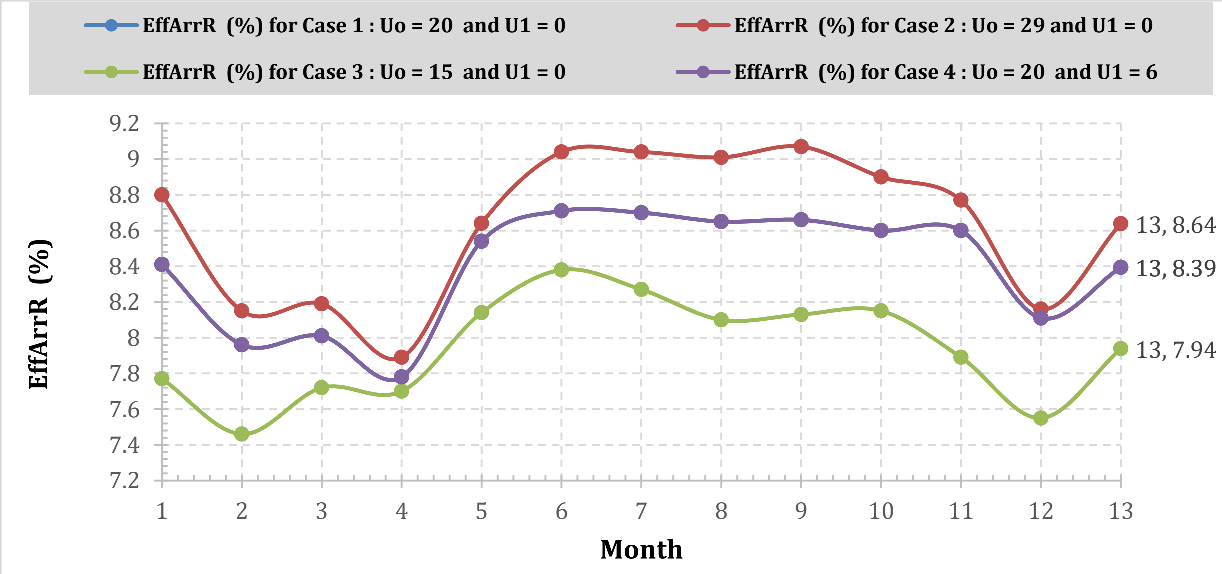


Figure 12 The PV array efficiency, EffArrR (%) for the four different thermal loss factor settings

Table 7 The System Efficiency, **EffSysR(%)** for the four different thermal loss factor settings

	Month	EffSysR(%) for Case 1 : Uo = 20 and U1 = 0	EffSysR(%) for Case 1 : Uo = 29 and U1 = 0	EffSysR(%) for Case 3 : Uo = 15 and U1 = 0	EffSysR(%) for Case 4 : Uo = 20 and U1 = 6
January	1	7.67	7.67	7.67	7.67
February	2	7.32	7.32	7.32	7.32
March	3	7.38	7.38	7.38	7.38
April	4	7.58	7.58	7.58	7.58
May	5	7.84	7.84	7.84	7.84
June	6	8.96	8.96	8.96	8.96
July	7	9.9	9.9	7.87	9.9
August	8	6.9	7.42	7.41	6.9
September	9	8.52	8.52	8.52	8.52
October	10	8.39	8.39	7.1	8.39
November	11	8.07	8.07	7.71	8.07
December	12	7.54	7.54	7.54	7.54
Year Average		8.01	8.05	7.72	7.97

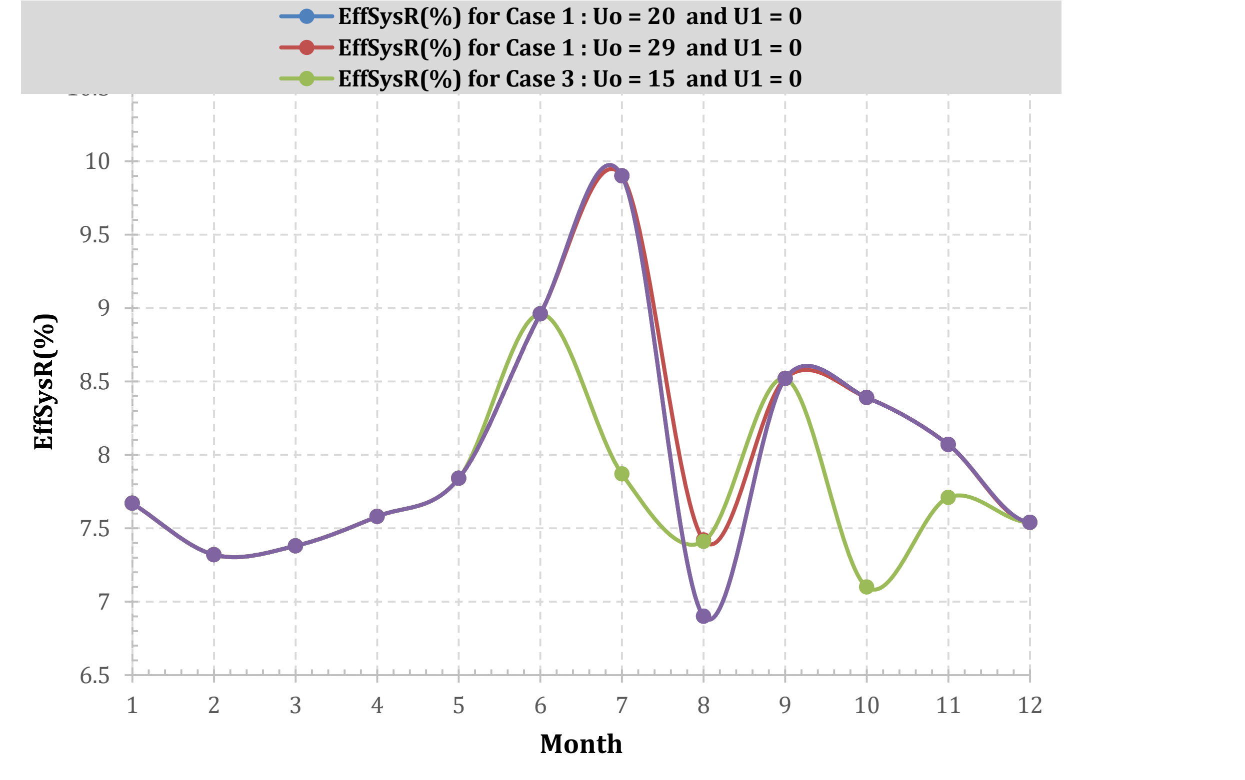


Figure 13 The System Efficiency, **EffSysR(%)** for the four different thermal loss factor settings

4. CONCLUSION

An analysis of the impact of thermal loss factor setup on a standalone PV power system used to supply electric power to a microfinance bank is presented. The PVSyst software is used to simulate the sizing and thermal loss analysis of the standalone power system for different PV installation setups. Particularly, the study considered four different thermal loss factor setups, namely; Case I; Semi-integrated with air duct behind with Uo = 20 and U1 = 0; Case II: free-standing arrays which is the current PVSyst default with Uo =29 and U1 = 0; Case III: integrated PV module with fully insulated back or for a close roof mounted fully insulated PV arrays with Uo =15 and U1 = 0; and Case IV: old version of PVsyst default value with Uo =20 and U1 = 6.

In all, case II which is for free standing PV installation gave the highest PV array efficiency, highest system efficiency, lowest PV module temperature rise above the ambient temperature and finally the lowest thermal loss. On the other hand, case III which is for integrated PV module installation with fully insulated back and also the setting for close roof mounted PV installation gave the lowest PV array efficiency, lowest system efficiency, highest PV module temperature rise above the ambient temperature and finally the highest thermal loss. The implication is that rooftop PV installation suffers more losses than the free standing PV installation. As such, while space is conserved by re-using the roof for the PV installation, there is a trade-off in the reduction in the PV array efficiency and system efficiency.

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