Modeling of Combined Earth Tube Heat Exchanger and Solar Photovoltaic with Blower for Maintaining a Hospital Ward

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Abstract:- The aim of the contribution of this paper is the use of a blower (pumping ambient air through a series of pipes through the earth's crust at the required depth) and electrical appliances which are powered by solar photovoltaic modules. The net air temperature obtained by pumping with a blower is supplied to a 300 m^3 hospital ward with 13 patients, 13 nurses, 1 nurse and 1 doctor. The analysis is carried out for January and May. In January, the ambient air is pumped by a blower to a depth of 3.04 m through pipes having a temperature of 24^{o}C[23]. The ambient air reaches 24^{o}C in January and is sent to a hospital ward maintained at 24^{o}C. In May, after passing the ambient air for a certain length at a depth of 3.04m, it reaches 24^{o}C and the same air again is passed through well water situated at a depth of 10m[11] from the earth's surface with a temperature of 18^{o}C[12] and with the result after passing a certain length and is pumped to hospital ward maintained at 18 ^{o}C. For the operation of the blower and electrical appliances, it is sufficient to have 7328 modules in parallel and 2 modules in series of SW280 solar photovoltaic modules, and the remaining extra current after meeting the requirement of the blower and electrical appliances is stored in the rechargeable battery. The amount of electric charge stored and discharged by the rechargeable battery in January and May is 63672.459Ah, 16881.932Ah and 70080.245Ah, respectively 39523.542Ah with a battery capacity of 191708.798Ah..

***Keywords**:- Blower; Electrical; Hospital Ward; SW280 Solar Photovoltaic; Rechargeable.*

I. INTRODUCTION

Applications of earth tube system/earth tube heat exchanger have advantage of utilizing thermal energy of earth's crust for the various needs. Many researchers have utilized this concept for obtaining required thermal energies. Also if earth tube system along with solar photovoltaic system is incorporated, it gives an added advantage of both electrical powers from solar photovoltaic system along with thermal energy from earth tube system. Many people/researchers have used the combined technologies to satisfy their needs.

In [1] authors proposed two novel combined configurations of the building integrated photovoltaic thermal (BIPVT) and compound earth-air heat exchanger (EAHE) system operating in two modes, i.e. heating and cooling modes. In [2] authors developed a simplified mathematical model for studying round the year effectiveness of photovoltaic/thermal (PV/T) and earth air heat exchanger (EAHE) integrated with a greenhouse, located at IIT Delhi, India. In [3] it dealt with an experimental outdoor annual performance evaluation of 2.32 kWP photovoltaic (PV) power system situated at solar energy park in New Delhi composite climatic conditions where PV system helped to operate the daily electrical load nearly 10 kW h/day comprising of various applications such as electric air blower of an earth to air heat exchanger (EAHE) used for heating/cooling of adobe house, ceiling fan, fluorescent tube-light, computer, submersible water pump, etc. Application of multi-objective optimization of a hybrid building integrated photovoltaic/thermal (BIPVT) system and earth-air heat exchanger (EAHE) was studied in [4]. Design of a coupling system of an earth-to-air heat exchanger with a simple photovoltaic array was made in Athens, Greece during a summer period in [5]. In [6] authors attempted to investigate the theoretical and practical performances of the photovoltaic/thermal (PV/T) system coupled with earth water heat exchanger (EWHE) cooling system for the conditions of semi-arid region of Pilani, Rajasthan.

In the current work, ambient air in January is pumped by a given blower present on the earth's surface through a series of pipes passing through the earth's crust at a depth of 3.04 m at a temperature of 24 °C[23]. At a depth of 3.04 m, the ambient air attains 24^{o}C in January, and this 24^{o}C air is received by 300 m^3 hospital ward having 13 patients, 13 attendants, 1 nurse and 1 doctor which is pumped by the same blower. In January 2 fridges and 10 LED bulbs are used throughout the day. In May, ambient air is pumped by the same given blower that is present at the earth's surface through a series of pipes to a depth of 3.04 m into the ground at a temperature of 24 °C. At a depth of 3.04 m, the ambient air reaches 24^{o}C in May and this 24^{o}C air passes through well water located at a depth of 10 m [11] maintained at 18^{o}C [12] and the thus obtained 18^{o}C air is received by a 300 m^3 hospital ward having 13 patients, 13 attendants,1 nurse and 1 doctor. In May beside 2 fridges and 10 LED bulbs, 14 ceiling fans are used throughout the day. The investigation is conducted for the city of Guwahati, which is located in the state of Assam, India.

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II. SYSTEM LAYOUT

The assumed volume of a hospital ward is 300 m^3 having number of air changes per 24 hours being 3.86[7], i.e. the number of air changes per second being 0.0134 m^3/s. Also in hospital ward there are 13 patients, 13 attendants, and 1 nurse and 1 doctor. Ventilation requirement per person is 0.0095 m^3/s[7]. Hence total ventilation for 28 persons is 0.266 m^3/s. Therefore total air circulation is 0.2794 m^3/s. Also in hospital ward 14 ceiling fans of 55 W each [24], 2 fridges of 250 W each[25] and 10 LED bulbs of 9 W each are present.

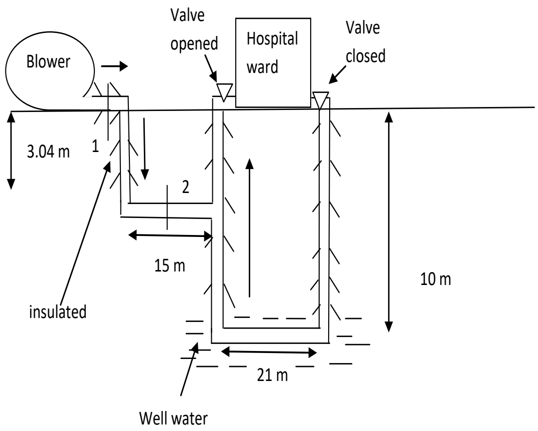

Fig.1. Layout diagram of a ground pipe heat pipe for warm air supply to a hospital ward in January

In Fig. 1, ambient air in January with a relative humidity of 79%[8] is pumped by a blower from 1 to 2. At 2, the ambient air attains a temperature of 24 ºC after overcoming a horizontal distance of 15 m, and this air is sent to 300 m^3 of hospital department with a relative humidity of 40%[9]. The radius of the pipe and the velocity throughout the range are considered to be 0.02 m and 0.148 m/s, respectively. The air density at 24 ºC is obtained from [10] having the remaining sections of the pipe as thermally insulated. In January 2 fridges, 10 LED bulbs are operated throughout the day and ceiling fans are not used.

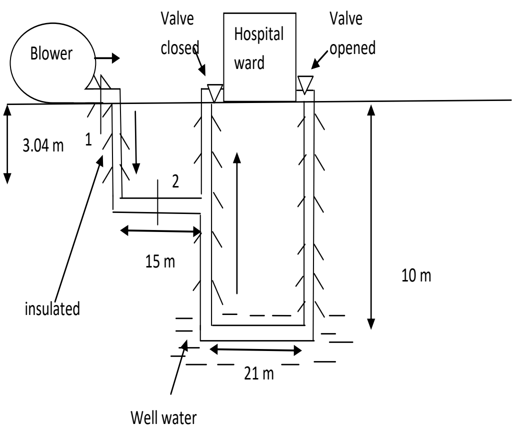

Fig.2. Layout diagram of a ground pipe heat pipe for cold air supply to a hospital ward in May.

In Fig. 2, ambient air in May with a relative humidity of 75%[8] is pumped by blower from 1 to 2. After reaching 24°C, the air at a depth of 3.04 m at 2, passes through well water at 3 located at a depth of 10 m[11] at 18ºC[12] and overcoming a horizontal distance of 21 m and is sent to a 300 m^3 hospital ward with a relative humidity of 50%[9]. The radius of the pipeline and the speed in the entire range are considered to be 0.02 m, 0.105 m/s. respectively. The density of air at 18 ºC is obtained from [10] with the remaining sections of the pipe as thermally insulated. In May 2 fridges, 10 LED bulbs and 14 ceiling fans are operated throughout the day.

Fig. 3 shows the power source of the blower and the electrical components of the hospital ward with a photovoltaic system. During the sunshine hours, the solar radiation falls on the solar photovoltaic modules generating the current I_{PV}. The current demand by the blower (I_{B1}) and electrical appliances (I_{B2}) is obtained after passing the current through the charge controller and the inverter. The excess current after meeting the blower (I_{PV}-I_{B1}) and electrical consumers (I_{PV}-I_{B2}) is received by the rechargeable battery for storage. During night time/non-sunshine hours, power of blower (I_{B1}-I_{PV}) and electrical appliances(I_{B2}-I_{PV}) is obtained from the rechargeable battery after passing the current through the charge controller, inverter.

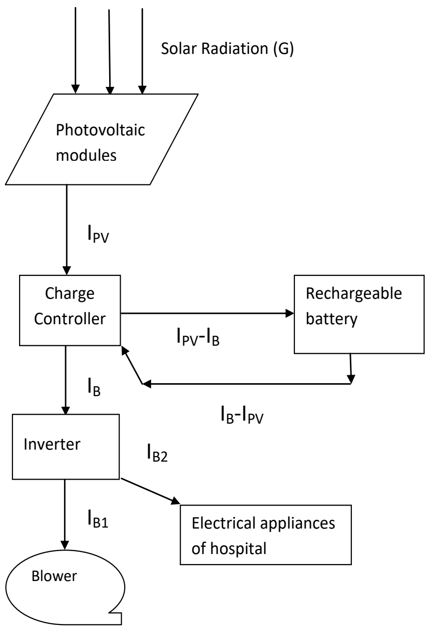

Fig.3. Scheme of the photovoltaic system for powering the blower and electrical appliances of the hospital ward.

III. MODELING OF COMBINED SYSTEM

In Fig. 1, ambient air in January comes from the blower at 1 having enthalpy h_1(kW) and passes through a pipe at a depth of 3.04 m where at a depth of 3.04 m, ambient air travels a horizontal distance of 15 m reaching a temperature of 24ºC at 2 and thereby this 24ºC air obtained at 2 is admitted to a hospital ward in January at an enthalpy of h_2(kW).

$$h_1 = 0.2794 \times \rho_{a,Jan} \times (1.006 \times T_{Jan} + x_{Jan}(2501 + 1.84 \times T_{,Jan})) \quad (1)$$

$$h_2 = 0.2794 \times \rho_{a,24} \times (1.006 \times 24 + x_{24}(2501 + 1.84 \times 24)) \quad (2)$$

Where, 1.006- air's specefic heat (kJ/kg°C), 2501-water's latent heat of vaporization (kJ/kg), 1.84-water vapour's specefic heat (kJ/kg°C), T_{Jan}-January's ambient temperature, x_{24} is absolute humidity at 24°C(40% relative humidity) and x_{Jan} is absolute humidity at ambient temperature of Guwahati city for January, $\rho_{a,Jan}$-dry air density at ambient temperature in January, $\rho_{a,24}$-dry air density at 24°C.

$$x_{Jan} = \frac{0.622 \times 0.79 \times \rho_{w,Jan}}{\rho_{a,Jan} - \rho_{w,Jan}} \quad (3)$$

Where, 0.79 is January's relative humidity considered at ambient temperature, $\rho_{w,Jan}$-water vapour density at ambient temperature in January, $\rho_{a,Jan}$-dry air density at ambient temperature in January.

It can be seen that ρ_w (water vapour density)at any temperature(T)in °C is obtained from equation 4,

$$\rho_w = \frac{0.0022 \times P_w \times 1000}{T + 273.15} \quad (4)$$

Where P_w- water vapour pressure at T in °C in kPa[13] and ρ_a (dry air density) at any temperature(T)in °C is obtained from [10].

The blower power requirement for air pumping at enthalpy h_1 to enthalpy h_2 is given by:

$$W_{b1} = \frac{(h_2 - h_1)}{0.68} \quad (5)$$

Where, 0.68- centrifugal blower's peak efficiency [14].

Power required by electrical appliances is given by :

$$W_{b2} = P_{fridge} \times 2 + P_{LEDbulbs} \times 10 \quad (6)$$

Where,P_{fridge}-power of a fridge, $P_{LEDbulbs}$-power of a LED bulb being 250 W, 9 W respectively.

In Fig. 2, the ambient air in May comes from a blower at 1 having enthalpy h_1(kW) and passes through a pipe at 2 at a depth of 3.04 m. At 2, it travels a horizontal distance of 15 m and reaches a temperature of 24°C. This 24°C air passes through well water at 3 at a depth of 10 m. After traveling a distance of 21 m the 24°C water at 3 reaches a temperature of 18°C this air at 18°C is pumped by the same blower to the hospital ward in May at an enthalpy of h_3(kW).

$$h_1 = 0.2794 \times \rho_{a,May} \times (1.006 \times T_{May} + x_{May}(2501 + 1.84 \times T_{,May})) \quad (7)$$

$$h_3 = 0.2794 \times \rho_{a,18} \times (1.006 \times 18 + x_{18}(2501 + 1.84 \times 18)) \quad (8)$$

Where, 1.006- air's specefic heat (kJ/kg°C), 2501-water's latent heat of vaporization (kJ/kg), 1.84- water vapour's specefic heat (kJ/kg°C), T_{May}- May's ambient temperature, x_{18} is absolute humidity at 18°C(50% relative humidity) and x_{May} is absolute humidity at ambient temperature of Guwahati city for May, $\rho_{a,May}$-dry air density at ambient temperature in May, $\rho_{a,18}$-dry air density at 18°C.

$$x_{May} = \frac{0.622 \times 0.75 \times \rho_{w,May}}{\rho_{a,May} - \rho_{w,May}} \quad (9)$$

Where, 0.75 is May's relative humidity considered at ambient temperature, $\rho_{w,May}$-water vapour density at ambient temperature in May, $\rho_{a,May}$-dry air density at ambient temperature in May.

The blower power requirement for air pumping at enthalpy h_1 to enthalpy h_3 is given by:

$$W_{b1} = \frac{(h_1 - h_3)}{0.68} \quad (10)$$

Where, 0.68- centrifugal blower's peak efficiency [14].

Power required by electrical appliances is given by :

$$W_{b2} = P_{fridge} \times 2 + P_{LEDbulbs} \times 10 + P_{fan} \times 14 \quad (11)$$

Where, P_{fridge}-power of a fridge, $P_{LEDbulbs}$-power of a LED bulb, P_{fan}- power of a ceiling fan being 250 W, 9 W, 55 W respectively.

The required detailed calculations for SW280 solar PV modules and specifications are obtained from [15] and [16]. Solar radiation and wind speed information for Guwahati city are obtained from [17] and [18] respectively. The average solar radiation values for January and May for horizontal surface are obtained from [17], which are 4.17 kWh/m^2/day and 5.31 kWh/m^2/day. Hourly pattern and variation of solar radiation is studied and calculated from [19].

The number of SW280 photovoltaic modules needed in series (N_s) is given by:

$$N_s = \frac{48}{V_{mod}} \quad (12)$$

Where 48-system voltage of the entire configuration and V_{mod}-maximum voltage of the SW280 module[16].
The current demand for photovoltaic modules (Ispv) is given by:

$$I_{spv} = \frac{(W_{b1} + W_{b2}) \times 1.25}{48 \times 0.85 \times 0.85 \times 7 \times 0.85} \quad (13)$$

Where, W_{b1}-total blower power(in W) per day, W_{b2}-total power consumed by electrical appliances(in W) per day 1.25-module derating factor[20], 48-system voltage, 0.85-power factor, 0.85-inverter efficiency,7-average hours of sunshine in Guwahati[21], 0.85-charge controller efficiency.

The number of photovoltaic modules SW280 in parallel (Np) is given by:

$$N_p = \frac{I_{spv}}{I_{\text{mod}}} \quad (14)$$

Where, I_{mod}- maximum current of the SW280 module[16]

IV. RESULTS AND DISCUSSIONS

TABLE I. TEMPERATURE, ENTHALPY AND BLOWER PUMPING POWER VARIANTS FOR JANUARY

Time(inHours)	$T_{amb,Jan}$(°C)[22]	h_1 (k W)	h_2 (k W)	$(h_2$-$h_1)$ (k W)	W_{b1} (k W)
12:30 AM	15	9.732	11.959	2.227	3.275
3:30 AM	16.111	10.418	11.959	1.541	2.265
5:30 AM	20	12.977	11.959	-1.018	-1.496
8:30 AM	22.777	14.964	11.959	-3.005	-4.418
11:30 AM	18.333	11.85	11.959	0.109	0.16
2:30 PM	17.777	11.485	11.959	0.474	0.697
5:30 PM	13.888	9.058	11.959	2.901	4.265
8:30 PM	13.333	8.73	11.959	3.229	4.749

TABLE II. ELECTRICAL DISCHARGE AND BATTERY CHARGE VARIANTS IN JANUARY

Time(in Hours)	Discharged current from battery(Ah)	Chraged current to battery(Ah)
12:30 AM	4228.158	0
3:30 AM	4220.964	0
5:30 AM	4194.148	0
8:30 AM	0	13844.308
11:30 AM	0	27536.862
2:30 PM	0	20416.628
5:30 PM	0	1874.661
8:30 PM	4238.662	0

Table I shows the variation of enthalpies at the blower outlet (state 1)(h_1) and inlet (state 2)(h_2) to a 300 m^3 hospital ward in January. The change in blower performance is also shown. It is observed that h_1 increases with increasing T_{Jan} due to increasing x_{Jan} whereas h_2 remains constant. At 5:30 AM and 8:30 AM $(h_2$-$h_1)$ will be negative because x_{24} at 2 is less than x_{Jan} at 1, which indicates that the heat is removed through the pipe at a depth of 3.04 m to the earth's soil at 24 °C. The energy consumed by the electrical components remains the same throughout the day.

Table II shows the battery's discharging and charging pattern in January. It is observed that the discharged current decreases from 12:30 AM to 5:30 AM as W_{b1} decreases from 12:30 AM to 5:30 AM. At 8:30 PM the discharged current is found to be maximum because W_{b1} is maximum. The hourly availability of sunlight is considered from 6:00 AM to 6:00 PM. It can be seen that the battery charged increases from 8:30 AM to 11:30 AM, decreases from 11:30 AM to 2:30 PM, and decreases again from 2:30 PM to 5:30 PM as solar radiation intensity increases from 6:00 AM to 12:00 PM and decreases again from 12:00PM to 6:00 PM. The power consumed by electrical appliances W_{b2} remains the same.

TABLE III. TEMPERATURE, ENTHALPY AND BLOWER PUMPING POWER VARIANTS FOR MAY

Time (inHours)	$T_{amb,Jan}$(°C)[22]	h_1 (k W)	h_2 (k W)	h_3 (k W)	$(h_1$-$h_3)$ (k W)	W_{b1} (k W)
12:30 AM	23.33	14.988	12.953	9.555	5.433	7.99
3:30 AM	25	16.244	12.953	9.555	6.689	9.836
5:30 AM	30	20.365	12.953	9.555	10.81	15.898
8:30 AM	28.33	18.921	12.953	9.555	9.366	13.773
11:30 AM	28.889	19.398	12.953	9.555	9.843	14.475
2:30 PM	25.55	16.668	12.953	9.555	7.113	10.461
5:30 PM	24.44	15.815	12.953	9.555	6.26	9.206
8:30 PM	24.44	15.815	12.953	9.555	6.26	9.206

TABLE IV. ELECTRICAL DISCHARGE AND BATTERY CHARGE VARIANTS IN MAY

Time(in Hours)	Discharged current from battery(Ah)	Charged current to battery(Ah)
12:30 AM	9749.401	0.0
3:30 AM	9762.562	0.0
5:30 AM	9805.76	0.0
8:30 AM	0.0	14711.907
11:30 AM	0.0	32214.85
2:30 PM	0.0	23153.488
5:30 PM	447.756	0.0
8:30 PM	9758.063	0.0

Table III shows the variation of enthalpies at the outlet of the blower (state 1)(h_1), state 2(h_2) and inlet (state 3)(h_3) to the 300 m^3 hospital ward in May. Also, blower pumping power is shown. It is observed that h_1 increases as T_{May} increases due to increase of x_{May} . However, h_2 remains constant throughout. It is observed that h_2 is more for May as x_{24} is more for May than January since relative humidity at May required is 50% compared to 40% in January. Also h_3 remains constant .As $(h_1$-$h_3)$ increases W_{b2} also increases. The power consumed by electrical components remains same throughout the day.

Table IV shows the discharge and charge fluctuations of the battery in May. The discharge current is observed to increase from 12:30 AM to 5:30 AM with increasing W_{b1}. It can be seen that the battery charged increases from 8:30 AM to 11:30 AM, decreases from 11:30 AM to 2:30 PM, and decreases again from 2:30 PM to 5:30 PM as solar radiation increases from 6:00 AM to 12:00 PM and decreases again to 6:00 PM. The power consumed by electrical appliances W_{b2} remains the same.

After comparing tables II and IV it is observed that current discharged from battery is more for May than January as in January W_{b1} is less and also W_{b2} is less due to non utilization of ceiling fans. Current charged to battery is more in May as solar radiation is more in May thereby producing more current (I_{PV}) compared to January.

From equation 12 and 14 the number of solar photovoltaic modules of model SW280 requirement in series and parallel are 2 and 7328 respectively. The cumulative amount of electric charge stored and discharged by the rechargeable battery in January and May is 63672.459Ah, 16881.932Ah and 70080.245Ah, 39523.542Ah respectively having a battery capacity of 191708.798Ah, battery charging efficiency of 90% and charge controller efficiency of 85%.

V. CONCLUSIONS

It is seen that for maintaining the hospital ward of 300 m^3 volume with 28 persons having 13 patients, 13 attendants,1 nurse and 1 doctor and 14 ceiling fans, 2 fridges, 10 LED bulbs, the number of SW280 solar photovoltaic modules requirement in series and parallel are 2 and 7328 respectively and 191708.7981Ah as battery capacity are sufficient. The analysis is done for January and May because in January and May, Guwahati city has minimum temperature, solar radiation; and maximum temperature, respectively solar radiation. So if the complete combined system works well at minimum and maximum state, the system will work well all year round. If the room volume, number of persons and electrical appliances are changed the requirement of solar photovoltaic modules and battery capacity will change accordingly.

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