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Modeling Of Solar Assisted Air Purifier For Room Air Conditioning Assisted By Polymer Electrolyte Membrane Fuel Cell And Electrolyzer

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Abstract: *The objective of the paper is to purify ambient air in the month of January and May in Guwahati city for an office room of 40 m^3 with 6 persons and 5 LED(light emitting diode) bulbs of 9W each throughout the day. In January ambient air is purified and brought to reference state of 40% relative humidity, 24°C by using an air purifier, air blower, and vapour compression refrigeration system using 134a as refrigerant. Similarly in May ambient air is purified and brought to reference state of 50% relative humidity, 18°C by using an air purifier, air blower, and vapour compression refrigeration system using 134a as refrigerant. The power required for operating the blower, 5 LED bulbs and vapour compression refrigeration compressor are obtained from 11 solar photovoltaic modules in parallel, 2 in series of model SW 280 assisted by 3.634 kW electrolyzer and one 382.368W PEM(polymer electrolyte membrane) fuel cell stack. The power required by gas compressor for pressurizing of hydrogen for storage produced by 3.634 kW electrolyzer is obtained from 1 solar photovoltaic module in parallel, 2 in series of model SW 280.*

Keywords – *Air, Electrolyzer, Fuel Cell, PEM(Polymer Electrolyte Membrane), Solar Photovoltaic, Vapour Compression.*

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I. INTRODUCTION

Air purifier are used for purifying ambient air or air coming from indutries. Usually ambient air may contain impurities lik dust, particulate matters, CO_2 etc. Hence purifying air is of great importance as inhaling impure air causes many diseases or side effects.

People/researcherers around the world have devised different ways and technologies for removing impurities from air. The present paper deals with air purification of an office room of 40 m^3 with 6 persons using fuel cell technology. Many researchers have worked on air purification by using fuel cell. In ref.[1] authors used solar chimney in desert areas of the Yazd city with high-intensity solar radiation for operating by considering the solid oxide fuel cell and solid oxide electrolysis cell for storing the surplus energy as hydrogen for the night times. In ref.[2] authors used a new solar-based fuel cell-powered oxygenation and ventilation system for COVID-19 patients by water splitting for generating the required oxygen through the operation of a proton exchange membrane water electrolyser. In ref.[3] authors used photocatalyst oxidation for removing gaseous formaldehyde (HCHO) a photocatalytic fuel cell (PFC) with a rotating photoanode. In ref. [4] authors used hydrogen fuel-cell vehicles (HFCVs) for improving air quality, health, and climate significantly by converting all U.S. onroad vehicles from gasoline vehicles. In ref.[5] authors developed a compact, 3-kW, purifier-integrated modular reformer for the building block of full-scale 30-kW or 50-kW methanol fuel processors for PEM(polymer electrolyte membrane) fuel cell vehicles for removing CO contamination.

In this paper, a system of photovoltaic modules, electrolyzer, PEM(polymer electrolyte membrane) fuel cell, gas compressor are used for powering of blower, compression refrigeration's compressor and LED bulbs for air purification.

II. SYSTEM LAYOUT

Fig. 1 shows a refrigeration plant where the enthalpy of air at the ambient temperature of Guwahati city leaving the blower and air purifier at *h1a* absorbs the heat dissipated by the refrigerant 134a in the condenser from 1 to 2 leaves at the enthalpy of air at 24 °C , *h1a* into the 40m^3 office room with 6 people. The relative air humidity considered at the inlet of the condenser is 79% [6] and at the outlet of the condenser is 40%[7]. The temperature of the evaporator (T_E) is maintained at 15°C, the temperature of the condenser (T_C) at 22°C. The operation of the VCR is already known and is therefore not explained here.

Fig. 2 shows a refrigeration plant where Guwahati's ambient air enthalpy leaving blower and air purifier at *h1a* rejects heat to refrigerant 134a in evaporator from 3 to 4 exits at 18°C air enthalpy *h1b* to 40m^3

office room with 6 people . The relative air humidity considered at the evaporator inlet is 75% [6] and at the evaporator outlet is 50%[7]. The temperature of the evaporator (T_E) is maintained at 15^{o}C, the temperature of the condenser (T_C) at 30^{o}C.

Fig. 3 shows the distribution where the solar radiation hitting the solar photovoltaic modules (SPVs) during the solar hours generates the current I_{PV}. Through the charge controller, the current required by the VCR compressor, blower and 5 LED bulbs ($I_C + I_B + I_E$) goes to the VCR compressor, blower and bulbs after passing through the inverter and the extra current (I_{PV}- ($I_C + I_B + I_E$) goes to the PEM electrolyzer where water present in electrolyzer is dissociated into hydrogen and oxygen. Hydrogen produced is sent to storage tank in compressed form which derives the power for compressing by gas compressor. Gas compressor derives its current I_G for compressing hydrogen from extra photovoltaic modules shown in figure 3.

During the night, the current required by the compressor, blower and 5 LED bulbs ($I_C + I_B + I_E - I_{PV}$) comes from PEM fuel cells where fuel cell produces the required current by consuming hydrogen that gets stored in storage tank during day time.

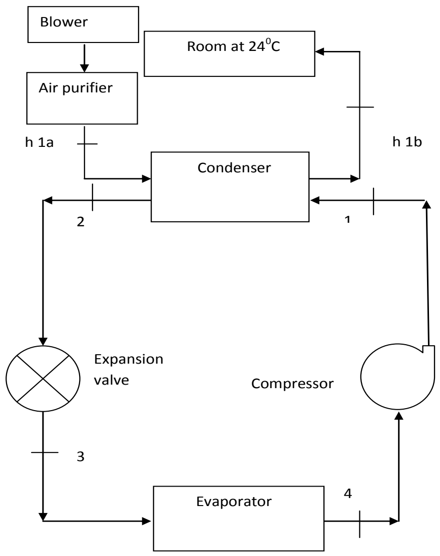

Fig. 1. VCR schematic with R134a as refrigerant for office room to be maintained at 24^{0}C for January

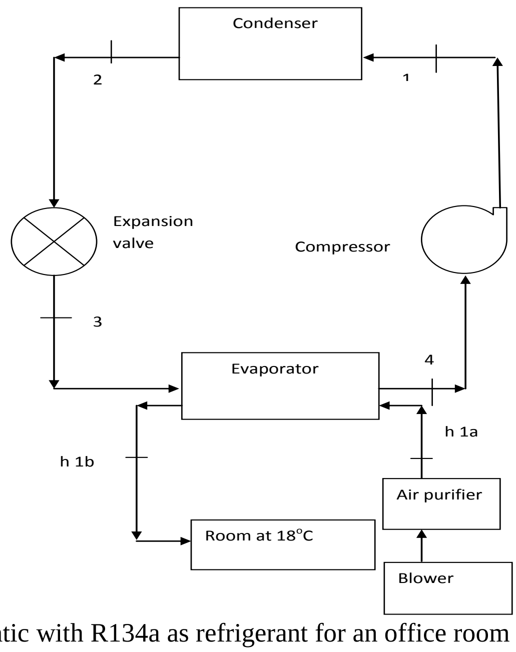

Fig. 2. VCR schematic with R134a as refrigerant for an office room to be maintained at 18^{0}C for May

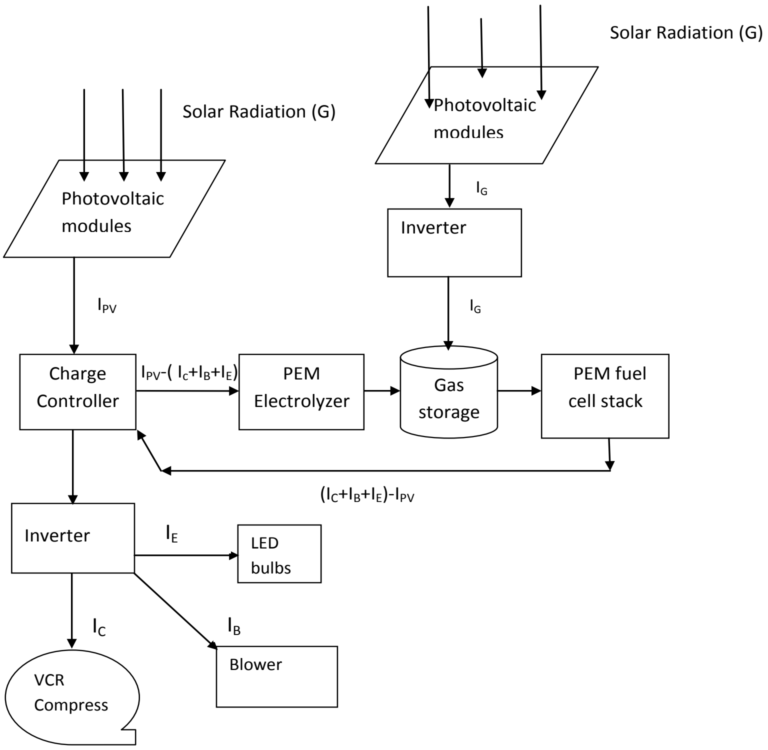

Fig.3. Schematic view of solar photovoltaic modules with charge controller, PEM electrolyzer, PEM fuel cell and inverter for powering compressor, blower and LED bulbs during day time/night time

III. MODELING

3.1 Modeling of air filter

The air cleaner is used to clean the air coming from the environment and discharged to the vapor compression refrigeration system with refrigerant R134a to maintain the desired condition of the office room. The volume of the room is considered to be 40 m^3 with the number of air changes per 24 hours being 15.29[8]. The number of air changes per second is therefore 0.00707 m^3/s for 6 people with a ventilation need of 0.0071 m^3/s for each person[8]. The total air circulation is therefore 0.0496 m^3/s.
The schematic view of air filter is shown below.[9]

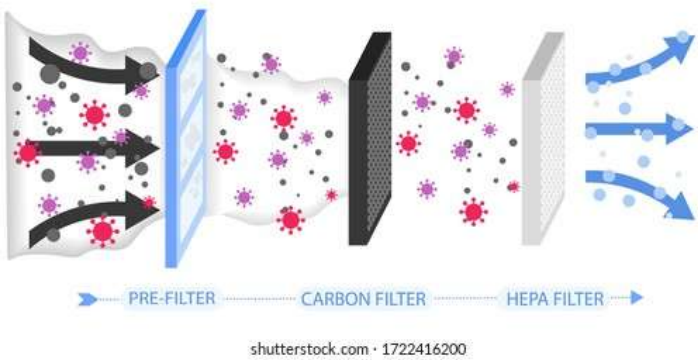

Fig.5. Schematic layout of air filter

The pore sizes of the pre-filter, carbon filter and HEPA filter are assumed to be 10 microns[10], 0.5 microns[11] and 0.3 microns[12]. For effective filtration, an air speed of 1.462 m/s is considered [13]. The surface area of the filter is therefore calculated to be 0.184 m x 0.184 m.

3.2 Modeling of photovoltaic modules and VCR system

Fig. 1 shows the layout of a compression refrigeration system in January with R-134a refrigerant. The analysis of the compression refrigeration system is already known and will be limited to the condenser, since in January the system works as a heat pump. In the condenser, the superheated R134a leaving the compressor at 1 leaves the condenser at 2. The enthalpy of the heat removed (h_1-h_2) kJ/kg is used by the enthalpy of the heat arriving at *h1b* (kJ/kg) and the leaving heat enthalpy at *h1a* (kJ/kg) to the room which is supplied by the blower.

$$h_{1b} = (1.006\times 24 + x_{24}(2501 + 1.84\times 24))\times m_{24} \quad (1)$$

$$h_{1a} = (1.006\times T_{Jan} + x_{Jan}(2501 + 1.84\times T_{Jan}))\times m_{Jan} \quad (2)$$

Where, 1.006-specefic heat of air(kJ/kg^{o}C), 2501-latent heat of vaporization of water(kJ/kg), 1.84-specefic heat of water vapour(kJ/kg^{o}C), T_{Jan}-ambient temperature in January(^{o}C), x_{24} is absolute humidity at 24^{o}C and x_{Jan} is absolute humidity at ambient temperature of Guwahati city for January, m_{24}-mass flow rate of air at 24^{o}C(kg/s), m_{Jan}-mass flow rate of air at ambient temperature in January.

$$x_{24} = \frac{0.622\times 0.4\times \rho_{w,24}}{\rho_{a,24} - \rho_{w,24}} \quad (3)$$

Where, 0.622- ratio of molar mass of water vapour and molar mass of dry air, 0.4 is the relative humidity of room considered at 24^{o}C, $\rho_{w,34}$-density of water vapour at 24^{o}C(kg/m^3), $\rho_{a,24}$-density of dry air at 24^{o}C(kg/m^3).

$$x_{Jan} = \frac{0.622\times 0.79\times \rho_{wJan}}{\rho_{a,Jan} - \rho_{w,Jan}} \quad (4)$$

Where, 0.622- ratio of molar mass of water vapour and molar mass of dry air, 0.79-relative humidity of ambient air's temperature in January, $\rho_{w,Jan}$-density of water vapour of ambient air's temperature in January(kg/m^3), $\rho_{a,Jan}$-density of dry air at ambient air's temperature in January(kg/m^3).

It is to be noted that ρ_w (density of water vapour)(kg/m^3) at any temperature(T)in ^{o}C is obtained from equation 5,

$$\rho_w = \frac{0.0022\times P_w \times 1000}{T + 273.15} \quad (5)$$

Where, 0.0022- reciprocal of individual gas constant of water vapour, P_w- pressure of water vapour at T in ^{o}C in kPa and ρ_a (density of dry air) at any temperature(T)in ^{o}C is obtained from [14].

Power requirement of blower for pumping air at enthalpy of h_{1b} to enthalpy of h_{1a} is given by :

$$W_b = \frac{(h_{1b} - h_{1a})}{0.68} \quad (6)$$

Where, 0.68- peak efficiency of centrifugal blower [15].

The condenser load(in W) is found by equation 6,

$$Q_h = (h_{1b} - h_{1a})\times 0.0496\times \rho_{a,Jan} \quad (7)$$

Where, 0.0496-number of air changes(m^3/s) for 40 m^3 room and 6 persons, $\rho_{a,Jan}$-density of ambient air in January(kg/m^3), $(h_{1b}-h_{1a})$ is in kJ/kg.

The ideal *COP*(coefficient of performance) of heat pump of figure 1 is :

$$COP_{HP} = \frac{T_C}{T_C - T_E} \quad (8)$$

Where, T_C-condenser temperature, T_E- evaporator temperature

Cooling load(Q_E)(in W) of figure 1 is :

$$Q_E = Q_h - \frac{Q_h}{COP_{HP}} \quad (9)$$

Ideal compressor load (W_{c1}) (in W)of figure 1 is :

$$W_{c1} = \frac{Q_E}{COP_{HP} - 1} \quad (10)$$

Or,

$$W_{c1} = m_r \times (h_1 - h_4) \quad (11)$$

Where, m_r- mass flow rate of refrigerant 134-a(kg/s), h_1- enthalpy of refrigerant 134-a in superheated state at saturation pressure corresponding to condenser temperature and at exit from compressor(kJ/kg), h_4-enthalpy of refrigerant 134-a at saturation vapour state corresponding to evaporator temperature(kJ/kg).

Mass flow rate of refrigerant (m_r) (in kg/s) is: $m_r = \frac{Q_E}{(h_4 - h_3)}$ (12)

Where, h_4-enthalpy of refrigerant 134-a at saturated vapour corresponding to evaporator temperature(kJ/kg), h_3-enthalpy of refrigerant 134-a at exit from expansion valve(kJ/kg).

Actual compressor load(W_c) (in W)of figure 1 is: $W_c = \frac{W_{c1}}{0.85}$ (13)

Where, 0.85- isentropic efficiency of centrifugal compressor[16]

Power required by electrical appliances is given by :

$$W_e = P_{LEDbulbs} \times 5 \quad (14)$$

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

Actual COP(coefficient of performance) of heat pump of figure 1 is :

$$COP_{a,HP} = \frac{Q_h}{W_c} \quad (15)$$

Fig. 2 shows the layout of a compression refrigeration system in May with R-134a refrigerant. The analysis of the compression refrigeration system is already known and will be limited to the evaporator, since in May the system works as a refrigerator. The enthalpy of heat absorbed by R134a (h_1-h_4) kJ/kg is used by removing the enthalpy of heat arriving in *h1a* and leaving with the enthalpy of heat in *h1b* to the room, which is supplied by the blower.

$$h_{1a} = (1.006 \times T_{May} + x_{May}(2501 + 1.84 \times T_{May})) \times m_{May} \quad (16)$$

$$h_{1b} = (1.006 \times 18 + x_{18}(2501 + 1.84 \times 18)) \times m_{18} \quad (17)$$

Where T_{May}-ambient temperature in May, x_{18} is absolute humidity at 18^{o}C and x_{May} is absolute humidity at ambient temperature of Guwahati city for January, m_{May}-mass flow rate of air at ambient temperature at May(kg/s), m_{18}-mass flow rate of air at 18^{o}C.

$$x_{18} = \frac{0.622 \times 0.5 \times \rho_{w,18}}{\rho_{a,18} - \rho_{w,18}} \quad (18)$$

Where, 0.622- ratio of molar mass of water vapour and molar mass of dry air, 0.5 is the relative humidity of room considered at 18^{o}C, $\rho_{w,18}$-density of water vapour at 18^{o}C, $\rho_{a,18}$-density of dry air at 18^{o}C.

$$x_{May} = \frac{0.622 \times 0.75 \times \rho_{w,May}}{\rho_{a,May} - \rho_{w,May}} \quad (19)$$

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

Power requirement of blower for pumping air at enthalpy of h_1 to enthalpy of h_2 is given by :

$$W_b = \frac{(h_{1a} - h_{1b})}{0.68} \quad (20)$$

Where, 0.68- peak efficiency of centrifugal blower [15].

The evaporator load(in W) is found by equation 21,

$$Q_e = (h_{1a} - h_{1b}) \times 0.0496 \times \rho_{a,May} \quad (21)$$

Where, (h_{1a}-h_{1b}) is in kJ/kg.

The COP of refrigerator of figure 2 is : $COP_R = \frac{T_E}{T_C - T_E}$ (22)

Compressor load (W_{c2}) of figure 2 is : $W_{c2} = \frac{Q_e}{COP_R}$ (23)

Or, $$W_{c2} = m_r \times (h_1 - h_4) \quad (24)$$

Where, m_r- mass flow rate of refrigerant 134-a(kg/s), h_1- enthalpy of refrigerant 134-a in superheated state at saturation pressure corresponding to condenser temperature and at exit from compressor(kJ/kg), h_4-enthalpy of refrigerant 134-a at saturation vapour state corresponding to evaporator temperature(kJ/kg).

Mass flow rate of refrigerant (m_r) (in kg/s) is: $m_r = \frac{Q_e}{(h_4 - h_3)}$ (25)

Where, h_4-enthalpy of refrigerant 134-a at saturated vapour corresponding to evaporator temperature(kJ/kg), h_3-enthalpy of refrigerant 134-a at exit from expansion valve(kJ/kg).

Actual compressor load(W_c) (in W)of figure 2 is: $W_{vsr,c} = \frac{W_{c2}}{0.85}$ (26)

Where, 0.85- isentropic efficiency of centrifugal compressor[16]

Power required by electrical appliances is given by :

$$W_e = P_{LEDbulbs} \times 5 \quad (27)$$

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

The detailed calculations for solar photovoltaic modules and specifications are available in [17] and [18] respectively. The solar radiation and wind speed data are obtained from [19] and [20].

Number of photovoltaic modules needed in series(N_s) is given by:

$$N_s = \frac{48}{V_{mod}} \quad (28)$$

Where 48 is the system voltage and V_{mod}-maximum voltage of the module.[21]

Amount of current required from photovoltaic modules(I_{spv}) is given by:

$$I_{spv} = \frac{(W_b + W_{vcr,c} + W_e) \times 1.25}{48 \times 0.85 \times 0.85 \times 7 \times 0.85} \quad (29)$$

Where, W_c-total compressor work(in W) in a day, 1.25-derating factor[22], 48-system voltage, 0.85-power factor, 0.85-inverter efficiency,7-average sunshine hours in Guwahati[23], 0.85-charge controller efficiency.

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

$$N_p = \frac{I_{spv}}{I_{mod}} \quad (30)$$

Where, I_{mod}- maximum current of the module[21]

3.3 Modeling of electrolyzer and PEM fuel cell

In electrolyzer water present in it is dissociated into hydrogen and oxygen gas by utilizing excess current after meeting blower's, VCR compressor's and 5 LED bulbs' current. For dissociating water by electrolyzer a number of electrolyzer cells are used in series.

The amount of hydrogen produced (in gm mol) with series of electrolyzer cells is given by[25]:

$$M_{electrolyzer} = \frac{(I_{PV} - I_{SPV}) \times N_{electrolyzer} \times \eta_{electrolyzer} \times 3600}{2F} \quad (31)$$

Where, (I_{PV}-I_{SPV})-excess current obtained after meeting blower, VCR compressor and 5 LED bulbs, $N_{electrolyzer}$-number of electrolyzer cells in series, $\eta_{electrolyzer}$-electrolyzer electrical efficiency[25], F-96500 C/mol.

The output voltage of a PEM fuel cell($V_{fuelcell}$) is given by[25]:

$$V_{fuelcell} = V_{Nerst,fuelcell} - V_{activation,fuelcell} - V_{ohmic,fuelcell} - V_{concentraion,fuelcell} \quad (32)$$

Where, $V_{Nerst,fuelcell}$- Nerst potential of PEM fuel cell, $V_{activation, fuel cell}$- activation voltage required for occurring of chemical reaction, $V_{ohmic,fuelcell}$-voltage generated due to resistance to the flow of current, $V_{concentration,fuelcell}$-voltage generated due to deficient supply of reactant at electrodes.

The above mentioned different potentials in equation(32) are obtained from [25].

The number of fuel cells connected in series forming a stack ($N_{fuelcell,series}$) is given by[25]:

$$N_{fuelcell,,series} = \frac{V_{system}}{V_{fuelcell}} \quad (33)$$

Number of fuel cell stacks needed in parallel ($N_{fuelcell,parallel}$) is given by [25]:

$$N_{fuelcell,parallel} = \frac{(I_{SPV} - I_{PV})}{I_{cell}} \quad (34)$$

Where, (I_{SPV}-I_{PV})- current requirement during night time, I_{cell}-current generated by single fuel cell.

The hydrogen consumed by a fuel cell stack ($M_{fuelcell}$) is given by [25]:

$$M_{fuelcell} = \frac{(I_{SPV} - I_{PV}) \times N_{fuelcell,series} \times 3600}{F \times \eta_{fuel,utilization}} \quad (35)$$

Where, $\eta_{fuel,utilization}$-fuel cell utilization factor (0.9)[25]

3.4 Modeling of gas compressor

In gas compressor hydrogen produced in electrolyzer is compressed and stored in a hydrogen gas storage tank due to the fact that hydrogen having low density will require large volume for storage. Hence by

using gas compressor hydrogen can be stored in small tank. The gas compressor derives its energy from extra solar photovoltaic modules shown in fig. 3.
The power required for running the gas compressor ($W_{gas,c}$) is given by[25]:

$$W_{gas,c} = \frac{M_{H_2} \times C_{p,hydrogen} \times T_{inlet}}{\eta_{g,compressor}} \times \left[\left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \quad (36)$$

Where, M_{H2}-mass flow rate of hydrogen(kg/s), $C_{p,hydrogen}$- specific heat of hydrogen at constant pressure (14.304 kJ/kg.K), T_{inlet}- inlet temperature of hydrogen to gas compressor, $\eta_{g,compressor}$-efficiency of gas compressor, P_2-exit pressure of hydrogen from gas compressor, P_1- inlet pressure of hydrogen to gas compressor(atmospheric pressure), γ -ratio of specific heats of hydrogen.

The current requirement for running gas compressor is obtained from separate photovoltaic module shown in figure with inverter.

$$I_{SPV,G} = \frac{W_{gas,c} \times 1.25}{48 \times 0.85 \times 7 \times 0.85} \quad (37)$$

Where, $W_{gas,c}$-total compressor work(in W) in a day, 1.25-derating factor[22], 48-system voltage, 0.85-power factor, 0.85-inverter efficiency,7-average sunshine hours in Guwahati[23].

By using equations 28 and 30, the number of photovoltaic modules is series and parallel is found to be both 1 and 1 with system voltage of 48 V.

IV. RESULTS AND DISCUSSIONS

Table 1. Temperature, enthalpy and blower, vapour compression refrigeration compressor and gas compressor pumping power for January

Time in hours	$T_{amb,Jan}$(°C)[24]	(h_{1b}-h_{1a}) kW	W_b (kW)	$W_{vcr,c}$ (kW)	$W_{gas,c}$(kW)
12:30 AM	11.667	0.750	1.103	0.016	0.0
3:30 AM	14.444	0.460	0.677	0.010	0.0
5:30 AM	20	-0.175	-0.258	-0.003	0.0
8:30AM	22.777	-0.528	-0.776	-0.010	0.262
11:30AM	20	-0.175	-0.258	-0.002	0.522
2:30PM	17.222	0.153	0.225	0.003	0.404
5:30PM	15.555	0.340	0.5	0.007	0.0024
8:30PM	12.222	0.693	1.019	0.015	0.0

Table 2. Hydrogen consumption and generation in January

Time in hours	Hydrogen consumption(gmol)	Hydrogen generated(gmol)
12:30 AM	13.641	0.0
3:30 AM	8.581	0.0
5:30 AM	2.531	0.0
8:30AM	0.0	20.882
11:30AM	0.0	47.915
2:30PM	0.0	35.278
5:30PM	0.0	0.205
8:30PM	12.642	0.0

Table 1 shows the variation of enthalpies at the outlet of the blower passing through the air filter and the entrance to a 40 m^3 office room with 6 people. The variation of blower work (W_b) along with VCR compressor work ($W_{vcr,c}$) is shown. It can be seen that (h_{1b}-h_{1a}) term decreases with increase in T_{Jan} as h_{1a} increases with T_{Jan} with increase in x_{Jan} and h_{1b} remains constant because the temperature at the outlet of the condenser remains constant, i.e. 24 °C and also x_{24}. At 5:30 AM, 8:30AM and 11:30AM, (h_{1b}-h_{1a}) it is negative which means that the heat is absorbed by the condenser. The blower work (W_b) and VCR compressor work($W_{vcr,c}$) is negative meaning that the blower and VCR compressor are being worked on. It can be seen that as the (h_{1b}-h_{1a}) term increases, the blower work (W_b) increases. Also, the actual work of the VCR compressor ($W_{vcr,c}$) increases if the blower work increases due to the increase in Q_h according to equation 7, which results in an increase in the mass flow rate of the refrigerant 134a. During day time hours i.e. 8:30AM, 11:30 AM, 2:30 PM, and 5:30 PM it is seen that gas compressor power requirement ($W_{gas,c}$) increases from 8:30AM to 11:30AM and decreases from 2:30 PM to 5:30 PM due to the fact that hydrogen production by electrolyzer increases from

8:30AM to 11:30AM and decreases from 2:30 PM to 5:30 PM as shown in table 2. As a result gas compressor power requirement increases from 8:30AM to 11:30AM and decreases from 2:30 PM to 5:30 PM shown by equation 36.

Table 2 shows the hydrogen consumption and hydrogen generation(in gmole/hour) for January. During non sunshine hours i.e. 12:30 AM, 3:30 AM, 5:30 AM it is seen that as blower work (W_b) and VCR compressor work ($W_{vcr,c}$) increases current requirement from PEM fuel cell by consumption of hydrogen increases. As a result, hydrogen consumption increases/decreases if blower work (W_b) and VCR compressor work ($W_{vcr,c}$) increases/decreases. Hydrogen generation increases from 8:30AM to 11:30AM and decreases from 2:30 PM to 5:30 PM due to the fact that solar radiation increases from 8:30AM to 11:30AM and decreases from 2:30 PM to 5:30 PM. As a result availability of excess current after meeting blower, VCR compressor, 5 LED bulbs (W_e) from photovoltaic modules for producing hydrogen increases from 8:30AM to 11:30AM and decreases from 2:30 PM to 5:30 PM.

Table 3. Temperature, enthalpy and blower, vapour compression refrigeration compressor and gas compressor pumping power for May

Time in hours	$T_{amb,Jan}$(^oC)[24]	(h_{1a}-h_{1b}) kW	W_b (kW)	$W_{vcr,c}$ (kW)	$W_{gas,c}$(kW)
12:30 AM	22.222	0.534	0.786	0.042	0.0
3:30 AM	29.444	1.544	2.271	0.122	0.0
5:30 AM	32.222	1.994	2.932	0.157	0.0
8:30AM	31.666	1.901	2.795	0.150	0.194
11:30AM	30.00	1.630	2.397	0.128	0.594
2:30PM	25.555	0.974	1.433	0.077	0.472
5:30PM	25	0.898	1.321	0.071	0.032
8:30PM	23.888	0.748	1.101	0.059	0.0

Table 4. Hydrogen consumption and generation in May

Time in hours	Hydrogen consumption(gmol)	Hydrogen generated(gmol)
12:30 AM	10.232	0.0
3:30 AM	28.555	0.0
5:30 AM	36.721	0.0
8:30AM	0.0	16.384
11:30AM	0.0	49.702
2:30PM	0.0	39.456
5:30PM	0.0	2.765
8:30PM	14.119	0.0

Table 3 shows the variation of enthalpies at the outlet of the blower through the air filter and at the entrance to a 40 m^3 office room with 6 people. The change in blower work (W_b), VCR compressor work ($W_{vcr,c}$) is also shown. It can be seen that (h_{la}-h_{1b}) increases with increasing temperature T_{May} and h_{1a} term increases with increasing x_{May}. However, h_{1b} remains constant because the evaporator outlet temperature remains constant, i.e. 18°C and also x_{18}. As a result blower work (W_b) and VCR compressor work ($W_{vcr,c}$) increases as Q_e increases according to Equation 21, resulting in an increase in mass flow rate of refrigerant 134a. During day time hours i.e. 8:30AM, 11:30 AM, 2:30 PM, and 5:30 PM it is seen that gas compressor power requirement ($W_{gas,c}$) increases from 8:30AM to 11:30AM and decreases from 2:30 PM to 5:30 PM due to the fact that hydrogen production by electrolyzer increases from 8:30AM to 11:30AM and decreases from 2:30 PM to 5:30 PM as shown in table 4. As a result gas compressor power requirement increases from 8:30AM to 11:30AM and decreases from 2:30 PM to 5:30 PM shown by equation 36.

Table 4 shows the hydrogen consumption and hydrogen generation(in gmole/hour) for January. During non sunshine hours i.e. 12:30 AM, 3:30 AM, 5:30 AM it is seen that as blower work (W_b) and VCR compressor work ($W_{vcr,c}$) increases current requirement from PEM fuel cell by consumption of hydrogen increases. As a result, hydrogen consumption increases/decreases if blower work (W_b) and VCR compressor work ($W_{vcr,c}$) increases/decreases. Hydrogen generation increases from 8:30AM to 11:30AM and decreases from 2:30 PM to 5:30 PM due to the fact that solar radiation increases from 8:30AM to 11:30AM and decreases from 2:30 PM to 5:30 PM. As a result availability of excess current after meeting blower, VCR compressor, 5 LED bulbs (W_e) from photovoltaic modules for producing hydrogen increases from 8:30AM to 11:30AM and decreases from 2:30 PM to 5:30 PM.

It can be seen that the blower work(W_b), VCR compressor work($W_{vcr,c}$) and gas compressor work ($W_{gas,c}$) is more for May than January.

The requirements of different components and parameters used are illustrated in table 5.

The amount of hydrogen produced/stored and hydrogen consumption in January and May are 104.28 gmol, 37.395 gmol and 108.307 gmol, 89.627 gmol respectively. Hydrogen production is more in May due to greater solar radiation and hence more amount of current was available for production of hydrogen by electrolyzer. Hydrogen consumption was more in May due to greater blower work and VCR compressor work, thereby requiring more hydrogen consumption by fuel cells in night time.

V. CONCLUSIONS

Based on the study it can be inferred that for maintaining a room of 40 m^3 at mentioned temperatures and humidity in January and May, a total of 11 photovoltaic modules in parallel, 2 in series(for powering blower, VCR compressor, 5 LED bulbs with electrolyzer), 1 photovoltaic modules in parallel, 1 in series(for gas compressor) along with 3.634 kW electrolyzer and one 382.368W PEM fuel cell stack are sufficient to operate the complete/whole system.

The study is done in January and May because January and May have the minimum solar radiation, temperature and maximum solar radiation and temperature respectively, so if the system works well in the minimum and maximum conditions, the system will work well throughout the year.

Table 5: Input parameters and ratings of different power system components

Components	Parameters/Components	Value/Ratings
Solar photovoltaic system	No. of photovoltaic modules in parallel	11
	No. of photovoltaic modules in series	2
	No. of photovoltaic modules in parallel for gas compressor	3
	No. of photovoltaic modules in series for gas compressor	2
Electrolyzer	No. of cells in series	75
	Cell area	86.4 cm^2 [25]
	Maximum current density	1.6 A/cm^2 [25]
	Membrane's dry thickness	178 micron[25]
	Electrolyzer input at 48 V	3.634 kW
Fuel cell	Exchange current density	10^{-4} A/cm^2 [25]
	Charge transfer coefficient of reaction	0.5 [25]
	Cell effective area	100 cm^2 [25]
	Operating current density	0.1 A/cm^2 [25]
	Number of fuel cell in one stack/series($N_{fc,series}$)	47
	Number of fuel cell stacks/parallel($N_{fc,parallel}$)	1
	Maximum output of each fuel cell stack	7.966 A, 382.368W
Hydrogen compressor	Isentropic efficiency	0.7 [25]
	Specific heat of hydrogen at constant pressure	14.304 kJ/kg.K [25]
	Inlet pressure	1.01325 bar
	Exit pressure	200 bar [25]
	Gas compressor rating at 48 V	0.696 kW
	No. of photovoltaic modules in parallel	1
	No. of photovoltaic modules in series	2

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