Design of Zero-Energy House for Mangalore Climatic Conditions

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Abstract—This paper discusses the design of a zero energy off-grid house suitable for Mangalore climatic conditions. As the electricity demands are increasing rapidly, the carbon emissions from the power plants are moving towards the atmospheric threshold value of 410ppm. This makes the concept of zero energy house vital in the current world. In this era, due to the abundant availability of renewable energy sources like solar and biomass energy, the realization of a zero-energy house is possible with ease. The paper focusses on finding the best suitable building material for the house, the total heat gain inside the house, use of solar vapour absorption system, natural lighting, biomass for cooking and solar PV for operating the necessary power requirements in the house. The size of the house for an average middle-class family in Mangalore is considered for analysis.

Index Terms—Bio-mass, heat gain, solar energy, time lag, zero-energy.

I. INTRODUCTION

Zero energy home is the term used for home that optimally combines commercially available renewable energy technology with state-of-the-art energy efficiency construction techniques [1]. Zero energy house is relevant in the current world scenario due to the increase in exploitation of fossil fuels, which leads to higher carbon emission in the atmosphere. Mangalore, located in the southern part of India, is the chief port city of the Indian state Karnataka. The average temperature in Mangalore is 36°C high and 22°C low. Within the past 5 years in Karnataka the electricity consumption has increased by 120% [2]. This proportionally increases the carbon emission in the atmosphere. As the demand for electricity and cost is increasing year by year and due to the extensive losses during transmission, off-grid stand-alone houses give us the most reliant option to fulfil our energy demands. In this paper, the complete design requirements for an off-grid zero energy house situated in Mangalore is considered.

II. METHODOLOGY

A. Selection of Suitable Materials for Walls and Windows of the Building

To build a zero-energy house, building bricks and window glass having suitable properties should be selected. Three factors are considered here: Decrement factor, Time Lag and CO₂ emission. The attenuation of heat wave from outside to inside is called decrement factor and the time taken by the heat wave to progress through the wall is called the time lag. The Total Equivalent Warming Index (TEWI) needs to be considered as there is CO₂ emission while manufacturing the building materials as well as while running the air conditioner in the building. Thus, a material having combination of low decrement factor, high time lag and minimum CO₂ emission has to be selected for the construction of buildings.

The types of bricks analysed were ordinary Burnt bricks, Laterite, Concrete, Fly ash lime gypsum (FALG), Soil cement and Sand-lime bricks. The heat transfer through building wall was assumed to be one dimensional transient heat conduction. A MATLAB code was developed using Finite Difference Method (FDM) to solve the above transient heat conduction problem. ANSYS Transient Thermal workbench was also used to solve the same problem. The boundary conditions imposed were: The inside ambient temperature = 25°C, the inside wall film coefficient = 7W/m²K, the outside wall film coefficient = 23W/m²K, thickness of wall = 25 cm. The results obtained from the MATLAB coding and ANSYS were compared and found to be closely matching.

Total Carbon dioxide emission includes the emissions during production and usage. The CO₂ emission during usage is calculated using the Energy Efficiency Rating (EER) of 4.5 (5 star rated AC), overall efficiency of thermal power plant: 0.25 and CO₂ emission for generation of 1kWh power in thermal power plant: 975grams.

From the analysis, it is found out that FALG is the most suitable material due to its perfect combination of less decrement factor, high time lag and lower carbon emissions compared to other materials. Also, the raw materials of FALG bricks come from the industrial wastes [3] (fly ash from thermal power plants and gypsum from phosphoric acid manufacturing plants), which pose serious disposal problems in India. Thus, usage of these wastes as raw materials would indirectly help the environment. It is also found out that fly ash bricks for walls and grey glass for the windows is the best combination to reduce heat gain inside the house to a significant extent [4].

B. Heat Gain and Cooling Load Inside the House

The study is carried out for a house in Mangalore (12.9141°N, 74.8560°E, GMT+5.5), one of the coastal cities of India, where the climate is generally hot and humid
throughout the year. The maximum global radiation received at Mangalore is in the month of April [13]. The analysis is carried out for April 22nd. With the help of a MATLAB code, the total solar radiation incident on the four walls, windows and the door are calculated, followed by the heat gain inside the house and the cooling load on air conditioner.

### Table I: Decrement Factor, Time Lag and Total CO₂ Emissions for Different Types of Bricks

<table>
<thead>
<tr>
<th>Brick Type</th>
<th>Decrement Factor</th>
<th>Time Lag (Hrs)</th>
<th>CO₂ emission During Production (g CO₂/Kg of Brick)</th>
<th>Indirect CO₂ emission During Usage (g CO₂/Kg of Brick)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand Lime Bricks</td>
<td>0.31</td>
<td>4.47</td>
<td>120</td>
<td>50.37</td>
<td>170.37</td>
</tr>
<tr>
<td>Laterite Bricks</td>
<td>0.56</td>
<td>5.44</td>
<td>0</td>
<td>31.75</td>
<td>31.75</td>
</tr>
<tr>
<td>FALG</td>
<td>0.40</td>
<td>8.16</td>
<td>0</td>
<td>53.44</td>
<td>53.44</td>
</tr>
<tr>
<td>Ordinary Bricks</td>
<td>0.55</td>
<td>5.86</td>
<td>270</td>
<td>52.42</td>
<td>323.42</td>
</tr>
<tr>
<td>Soil Cement Blocks</td>
<td>0.70</td>
<td>4.0</td>
<td>110</td>
<td>58.5</td>
<td>168.5</td>
</tr>
<tr>
<td>Concrete Blocks</td>
<td>0.56</td>
<td>5.31</td>
<td>159</td>
<td>51.68</td>
<td>210.68</td>
</tr>
</tbody>
</table>

1) Geometry and orientation of the house

The length of the house is oriented along the East-West direction, with a door on the east facing wall and two windows each on north and south facing walls.

Dimensions of the house = 10 m × 5 m × 4 m (Length × Width × Height).

Dimensions of the north facing windows = 2 m × 1.5 m × 0.003 m (Height × Width × Thickness).

Dimensions of the south facing windows = 1 m × 0.75 m × 0.003 m (Height × Width × Thickness).

Dimensions of the Door = 2 m × 1 m × 0.03 m (Height × Width × Thickness).

2) Materials used and their properties

<table>
<thead>
<tr>
<th>Building materials</th>
<th>Thermal conductivity (W/mK)</th>
<th>Density (kg/m³)</th>
<th>Specific heat (J/kg K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FALG</td>
<td>0.36</td>
<td>1700</td>
<td>857</td>
</tr>
<tr>
<td>RCC</td>
<td>1.58</td>
<td>2288</td>
<td>800</td>
</tr>
</tbody>
</table>

3) Heat generation inside the house

In a 4-member house, heat generation from the body and different appliances like Television, Electric Iron, Mixer and Biogas is considered, where they are rated 150 W, 640 W, 60W, 750W and 90 W of power respectively. It is assumed an average of 20 hours of occupancy inside the home where biogas will be used to cook for 6 hours in a day. The hourly usage of other appliances are obtained from Table VI. The net heat generated in a day is found to be 0.692 kW.

4) Other conditions applied

Outside film coefficient = 23 W/m²K, inside film coefficient = 7 W/m²K and Inside temperature to be maintained = 25°C.

We assume that there is no heat flux coming inside the house through its floor i.e. insulated floor. The heat gain inside the house was calculated with the help of equivalent temperature differential method [6] whose equations were coded and solved in MATLAB.

From Table IV, the heat gain in a day is found to be 59.28 kW hr and the cooling load is 2.47 kW. Considering the heat generation inside the house, the total heat gain in a day is 75.9 kW hr and the total cooling load is 3.162 kW (0.8192 tons).

C. Solar Vapour Absorption Air-Conditioning System

As the aim is to come up with a zero-energy house, the emphasis is given on a grid-free air-conditioning system. Vapour absorption system runs on low-grade thermal energy such as waste heat or solar energy. Since conventional absorption systems use natural refrigerants such as water or ammonia, they are environment friendly. In this system, a pair of water and Lithium Bromide is chosen as refrigerant-adsorbent as the difference between boiling points of the solvent and solution is greater than 300°C and there is no need of dephlegmator and rectifying column as in ammonia-water absorption system.

A basic setup of vapour absorption system is shown in Fig. 1. It works on the principle that addition of non-volatile solute (for example. Lithium Bromide) to solvent reduces the saturation pressure of solvent. In the absorption system, cooling is obtained by connecting two vessels containing solvent and solution respectively. At equilibrium, the pressure being almost same in both the vessels, temperature of the solvent will be less than that of the solution and hence, the refrigeration effect is produced at the solvent which evaporates by taking heat from the surrounding and flowing to the solution vessel where is absorbed by the solution. This process is continued as long as the composition and temperature of the solutions are maintained [10].
The comparison of vapour absorption system and vapour compression system with R134a as a refrigerant is done for 1 Ton refrigeration capacity. Following formulae were used [7].

For Absorption System,
\[ m = \frac{Q_e}{h_4 - h_3} \]  
\[ Q_e = mh_1 + m_{w3}h_7 \]  
\[ W_{pump} = (1+\varepsilon) m \times V_{soi} \times (P_c - P_e) \]

For Compression System,
\[ m = \frac{Q_e}{h_1 - h_4} \]
\[ \eta_{18} = (h_2 - h_1)/(h_2 - h_1) \]

By using equation (1), it is found that the power required to run a compressor (65% isentropic efficiency) in a compression system is 497.11 W and for an absorption system to run a solution pump is about 0.044W. Hence the vapour absorption system is more appropriate for zero energy house. Thermal energy required for operating the generator was found to be 3.95 kW for 1 Ton refrigeration.
and is to be provided by using solar flat plate collector. Collector plate area is calculated by using the following formula [8],

\[ A_c = \frac{q}{\eta_{sc}} \quad (3) \]

By using the equation (3) and substituting collector efficiency (\(\eta_{sc}\)) of 0.55 [9] and solar radiation intensity (I) of 675 W/m\(^2\) [13], area (\(A_c\)) is calculated as 10.65 m\(^2\).

### D. Natural Lighting

The sun provides a maximum illuminance of 100 kilolux on a clear day. Due to the abundant availability of natural sunlight during the day time, the aim is to bring that light into indoors, to reduce the usage of bulbs. The natural light illumination system can be divided into collecting, transmission and lighting components [11]. For collecting sunlight, static light concentrator having a prism like structure is used. Incident sunlight reaching the top surface undergoes reflections and refractions. The output ray passes through the optical transmission unit. Optical transmission unit consists of a coupler and optical fibres in a light pipe. The coupler is used to enhance the efficiency of light guided into the fibre. The light passes through the optical fibre following Total Internal Reflection (TIR). To distribute the light evenly inside the room, the TIR needs to break. The National Taiwan University of Science and Technology Electronics department experimentally analysed different types of dot patterns that can efficiently distribute the light. They derived 91% coupled efficiency with the designed coupler and fibre. An optical switch was also designed using a reflecting surface in the cubic structure. This can be used to charge solar cells or rechargeable LEDs to reduce the power requirement at night [11].

In Mangalore, experimentally we found out that at noon, when the sun has an altitude angle of 80\(^\circ\), the maximum illuminance observed near the window was 1900-2010 lux.

### E. Solar Photo-Voltaic System

For a stand-alone house, to meet the energy requirements for various appliances, Solar PV is considered. The region between the latitude of 40\(^\circ\)N and 40\(^\circ\)S is generally known as Solar Belt and has abundant solar radiation [13]. Mangalore being located at 12.9141\(^\circ\)N, geographically favours solar harvesting. From the climate report of Mangalore, it is found out that average sunshine hours obtained per day is 7.7 hours, maximum being in the month of January [14]. The average global radiation received in Mangalore is 690 W/m\(^2\)[13]. The standard test conditions at which the PV is tested is 1000 W/m\(^2\), which is the maximum radiation that can be incident on the face of the Earth. The panel generation factor is calculated as,

\[ \text{Panel Generation Factor} = \frac{\text{Sunshine Hours } \times \text{Available Radiation}}{\text{Standard Test Condition Radiation}} \quad (4) \]

From equation (4), Panel generation factor is found to be 5.313. Based on the results of a survey conducted in more than 1000 households in four districts of Karnataka, the commonly used appliances in houses were found out [15]. It is further optimized by choosing the best alternate appliance available in the market for our home.

#### TABLE VI: OPTIMIZED ANNUAL ENERGY CONSUMPTION OF HOUSEHOLD APPLIANCES

<table>
<thead>
<tr>
<th>Sl. no.</th>
<th>Appliance</th>
<th>Rating (Watt)</th>
<th>Numbers</th>
<th>Usage (hr/day)</th>
<th>Usage (hr/yr)</th>
<th>Consumption (kWh/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LED Bulb</td>
<td>9</td>
<td>6</td>
<td>4.5</td>
<td>1642.5</td>
<td>88.695</td>
</tr>
<tr>
<td>2</td>
<td>Fan</td>
<td>30</td>
<td>2</td>
<td>2.71</td>
<td>989.15</td>
<td>59.349</td>
</tr>
<tr>
<td>3</td>
<td>Electric Iron</td>
<td>750</td>
<td>1</td>
<td>0.67</td>
<td>244.55</td>
<td>183.412</td>
</tr>
<tr>
<td>4</td>
<td>Mixer</td>
<td>450</td>
<td>1</td>
<td>0.47</td>
<td>172</td>
<td>77.20</td>
</tr>
<tr>
<td>5</td>
<td>Refrigerator</td>
<td>100</td>
<td>1</td>
<td>22.33</td>
<td>8150</td>
<td>815.05</td>
</tr>
<tr>
<td>6</td>
<td>Television</td>
<td>79</td>
<td>1</td>
<td>3.93</td>
<td>1434</td>
<td>113.286</td>
</tr>
<tr>
<td>7</td>
<td>Water Pump</td>
<td>370</td>
<td>1</td>
<td>0.68</td>
<td>248</td>
<td>91.834</td>
</tr>
<tr>
<td>8</td>
<td>Battery Charger</td>
<td>5</td>
<td>2</td>
<td>3.25</td>
<td>1186</td>
<td>11.86</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>2198</td>
<td></td>
<td></td>
<td></td>
<td>1440.89</td>
</tr>
</tbody>
</table>

In Table VI, the hours of usage for LED bulbs are restricted to night time as natural lighting will be provided during the day time. Considering 30 days in a month, the total daily consumption of energy in the house is found to be 4 kWh. The pump requirement for Solar Vapour Absorption System is 0.044 W, which can be considered negligible. Using this knowledge, the minimum power requirement is calculated using the formula [16],

\[ W_p = \frac{\text{Total Energy Demand} \times \text{Margin}}{\text{Panel Generation Factor}} \quad (5) \]

Here, margin is taken as 1.2. Using equation (5), 903.45 Wp is obtained. SunPower\(^\oplus\) Solar panel of 335W nominal power, 21% efficiency, 67.9V open circuit voltage and 6.23A short circuit current is selected. 3 such panels are required to satisfy the power requirement. A stand-alone house requires four major components to use solar PV electricity in homes. PV array, Charge Controller, Battery Bank and Inverter and Distribution Panel. A charge controller regulates the flow of electric current to and from the battery to avoid over charging and over voltage, which can reduce the life of a battery. Since the panels are connected in series, the maximum voltage will be 67.9 \times 3 = 203.7V. Charge controller of Maximum open circuit voltage 250V and operational voltage of 12/24/48 V is chosen.
having 98.9% of Maximum Power Point Tracking (MPPT). Fixing the operational voltage as 24V, the minimum battery capacity is calculated using the following formula [16],

\[
\text{Battery Capacity} = \frac{\text{Total Energy Demand} \times \text{Margin} \times \text{Days of Autonomy}}{\text{Depth of Discharge} \times \text{Operational Voltage}}
\]  

(6)

(Since Lithium Ion batteries have more life expectancy, it is chosen. The depth of discharge is 85% and marginal loss is 1.2. In equation (6), Days of Autonomy refers to the number of days the battery will be functional without being recharged. It is assumed as 2 days. Using equation (6), minimum battery capacity is found to be 470.58 Ah. A battery of 12V and 100Ah capacity is chosen. Then 2 batteries need to be connected in series and 5 batteries should be connected in parallel giving the total number of batteries as 5x2=10 batteries. For a stand-alone house, the inverter depends on the total wattage of the house. From the Table 6., the total wattage is found to be 2198 W/day. For 90% efficient inverter, the minimum nominal power rating is 2442.23 W. An inverter by iMeshbean® of 2500 W rating and 24 VDC to output of 240 V AC is selected. It is stackable and hence can increase the power output by connecting in parallel if required. Using Solar Energy Data handbook, the optimum tilt angle of solar panels facing North, for Summer, Winter and Spring/Autumn seasons [17].

F. Bio-Gas

Due to the energy crisis caused by over consumption of fossil fuels, the world is in need of a green, efficient, carbon-neutral energy source to replace them. Kitchen waste is found to have a higher potential to produce biogas than cow dung. The amount of waste generated from the kitchen is found to be of sufficient quantity to generate enough biogas to use in the kitchen for cooking. This biogas generated is mainly composed of 50% to 70% methane \((\text{CH}_4)\), 30% to 40% carbon dioxide \((\text{CO}_2)\) and low amount of other gases [18].

As per Advisory Board of Energy (ABE), average requirement for cooking in India is 620 kcal per capita per day of useful energy [19]. The main source of energy was mainly liquefied petroleum gas (LPG) which is very expensive.

1) Comparison of energy spent per capita per day for cooking through LPG and biogas

After the LPG subsidy scheme by govt. of India, it is reported that 89% of families with 5 members per family use 7 LPG gas cylinders of 14.2 kg net gas each per year to suffice their energy requirement for cooking [20]. And it’s known that specific caloric value of LPG is 46.1 MJ/kg [21]. Hence,

Amount of energy required per day per capita for cooking through LPG = \(46.1 \times 7 \times 14.2 \times 5 / 365 = 2.51 \text{ MJ} = 599.294 \text{ kcal}\).

A daily quantity of 2 kg organic waste with leftover food as well as vegetable waste and fruit waste will be generated by a 5-member household [22]. This 2 kg of kitchen waste is fed to the biogas digester.

Gas production rate \((G)\): One kilogram of kitchen waste, if well digested yields 0.3 m\(^3\) of biogas [18]. The biogas production rate \((G)\) for the available kitchen waste, working with 2 kg/day is found to be 0.6 m\(^3\)/day. Calorific value of biogas produced by kitchen wastes is found to be 23 MJ/m\(^3\) [23].

So, energy generated per capita per day through Bio-waste = \(0.6 \times 23/5 = 2.76 \text{ MJ} = 658.756 \text{ kCal}\).

Therefore, biogas can suffice the energy requirement of cooking by producing more energy than LPG when calculated per capita for both the cases.

2) Design based on end-use-substitution of biogas for cooking

Design of biogas plant will be done for 5 houses of 5 members each for spatial, material and economic feasibility. In order to maximize biogas production, the kitchen waste and water should be fed in 1:2 ratio into the digester [24]. So, for 2 kg kitchen waste, 4 litre of water is to be fed.

The active slurry volume in the digester is directly related to the hydraulic retention time (HRT). This is the theoretical time that a volume of liquid waste added would remain in the digester.

Active slurry volume is therefore given by

\[
V_s = \frac{\text{HRT} \times 2 \times W}{1000}
\]  

(7)

For the kitchen waste, HRT = 30 days [18]. From equation (7), active slurry volume is found to be \(V_s = 1.8 \text{ m}^3\). (5 houses with 2 kg kitchen waste and 4 lt water i.e., 6 kg of feed). For design simplification, the standard volume 2 m\(^3\) which is nearer to calculated volume is selected. [25]

The relative values of height and diameter can be calculated from the volume of the digester given by,

\[
V_s = \left(\frac{2}{3}\right) \times D^2 \times H
\]  

(8)

In practice the ratio of D/H is taken as 2 [17].

<table>
<thead>
<tr>
<th>Material</th>
<th>Brick</th>
<th>Cement</th>
<th>Concrete (3/4&quot;)</th>
<th>Sand</th>
<th>GI pipe, nipple with socket</th>
<th>AC pipe</th>
<th>Epoxy Paint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td>Nos.</td>
<td>Bag</td>
<td>Cubic meter</td>
<td>Trolley</td>
<td>Set</td>
<td>Litre</td>
<td>meter</td>
</tr>
<tr>
<td>Quantity required</td>
<td>1000</td>
<td>15</td>
<td>1.25</td>
<td>1.2</td>
<td>1</td>
<td>10</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Therefore, from equation (8), height of digester, \(H = 0.8602 \text{ m}\) and diameter of the digester, \(D = 2 \times 0.8602 = 1.7204 \text{ m}\). For a proper alignment in a movable drum type plant, it is an appropriate design practice to keep gas holder diameter smaller by 6 inches (.1524 m) less than that of digester [24].

Diameter of gas holder should therefore be \(= 1.568 \text{ m}\). So, height of the gas holder = \((\text{Volume /Area}) = 0.9326 \text{ m}\). The Surface Area is calculated as the sum of the area of digester bottom, gasholder bottom and the annular space between the...
digestor and gas holder. The surface area required is found to be 4.5383 m².

For a middle-class family, the plan should be economical. Deenbandhu biogas plant is considered, which has a fixed dome type economical plant with less initial cost and better payback period. It consists of an inlet, mixing chamber, digester, gas holder and outlet chamber for slurry. It works on the principle of production of biogas by anaerobic digestion or fermentation of biodegradable materials such as biomass, manure, sewage, municipal waste, green waste, plant material and energy crops. The design consists of 2 spheres of different diameters, joined at their bases. This spherical design mainly nullifies the earth pressure and reduces the surface area required, which in turn minimizes cost of the biogas plant. Also, the structural strength of the spherical structure is comparatively more [24].

III. RESULTS AND DISCUSSIONS

For designing a zero-energy house, a wide pool of materials and their properties were considered. FALG turned out to be the most viable out of them as it has very less thermal conductivity and leaves less carbon footprint. Further, after performing the heat gain analysis of the building for 24 hours on each wall, total heat gain of 75.9 kWh (0.8192 tons) was obtained. The heat gain inside the building for two different building materials i.e. ordinary brick and FALG, were 3.37 kW and 2.47 kW respectively. Hence FALG bricks leads to lower cooling load for air conditioning system. After comparing the energy input requirements of pump and compressor of vapour absorption system and vapour compression system, it is clear that vapour absorption system is more suitable. Also, water is used as refrigerant in vapour absorption system which is eco-friendly. An absorption system of 1 Ton refrigeration capacity (3.5 kW) is found to be appropriate for the project. But the system of minimum refrigeration capacity available in the market is 10 Ton. So, 10 Ton refrigeration system will be used in a community of 10 houses. The total energy consumption of basic household appliances was found out and optimized, comparing with the best alternatives available in the market. From calculations, a total of 120 kW units was obtained per month. For an average of 7.7 sunshine hours, 3 solar panels each of 1.1 m² can be installed on the rooftop of the house for better results. A charge controller of maximum operational voltage 250V, 10 batteries each having 100Ah current and 12V voltage and an inverter of 2500W with 24 VDC to 240 VAC conversion is found to be ideal for the operation. A tilt angle of 100° towards North in summer and 54°, 77° towards South in winter and spring/autumn with respect to the vertical is found to be ideal for Mangalore. This study has shown that biogas production through organic waste not only meets our daily energy requirement, but also reduces the problems regarding solid waste management. For cooking through LPG, it is found that the present energy consumption per capita per day is around 599.29 KCal in theory. Whereas, around 658.75 KCal of useful energy generation per capita per day is possible even for a person in a middle-class family in India. Around 4.54 m² surface area of small-scale biogas plant is required for a community of 5 houses, which can be easily obtained in the backyard of home. Combining all the above design factors, a zero-energy house can be built.

IV. CONCLUSION

At the present rate of advancements in renewable technologies, net zero-energy houses will be our future reliance. Due to increase in the day to day consumption and demand of energy, zero energy buildings will be prominent for energy efficient constructions, which has better thermal comfort as well as eco-friendly nature. The efficiencies may vary under various climatic conditions, when the procedures are practically performed. Zero energy homes can be designed using new scientific techniques like solar glass, to increase the solar-energy input and phase change materials on walls, to improve the thermal mass. But the goal of zero energy buildings is not far from reality. When regions like Scandinavian countries have already deployed these techniques in large scale constructions, there is a need to spread awareness about the advantages of zero energy buildings. A laboratory simulation model will be done and the results will be compared with the theoretical results.

NOMENCLATURE

\[ A \]  
Circulation ratio

\[ h_2' \]  
Enthalpy at compressor outlet in actual process

\[ h_2 \]  
Enthalpy at compressor outlet in isentropic process

\[ h_1 \]  
Enthalpy of refrigerant at evaporator/generator outlet

\[ h_3 \]  
Enthalpy of refrigerant at evaporator inlet

\[ h_4 \]  
Enthalpy of refrigerant at evaporator outlet

\[ h_7 \]  
Enthalpy of solution at generator inlet

\[ h_8 \]  
Enthalpy of solution at generator outlet

\[ LED \]  
Light Emitting Diode

\[ LPG \]  
Liquified Petroleum Gas

\[ m \]  
Mass flow rate of refrigerant

\[ m_{ss} \]  
Mass flow rate of strong solution

\[ m_{wa} \]  
Mass flow rate of weak solution

\[ P_c \]  
Condenser pressure

\[ P_e \]  
Evaporator pressure

\[ PV \]  
Photo-Voltaic

\[ Q_e \]  
Refrigeration Capacity

\[ Q_g \]  
Heat required to run the generator

\[ W_{isentropic} \]  
Work to be supplied to compressor if the compression process is isentropic

\[ W_{actual} \]  
Work to be supplied to the compressor in actual process

\[ \eta_s \]  
Isentropic efficiency

REFERENCES


