CHAPTER 3
MATERIALS AND METHODS

3.0 EXERGY BASED INVESTIGATION OF DIFFERENT INSULATING MATERIALS FOR THE EFFICIENT PERFORMANCE OF THE BUILDING ENVELOPE

As, is evident that exergy analysis is a good way to establish energy flow in built structures. So, a few easily available and established insulating materials were identified for analysis, using the capability of MATLAB software. Exergy analysis of insulation materials as focal purpose of the work is presented in Chapter 4, for achieving thermal comfort of 23°C, inside the building envelope for entire duration of the day i.e. from 08:00 a.m. to 06:00 p.m. The analysis was carried out in two stages:

**CASE 1:** Comparing the installation of oven dry wood as an insulating material with the same oven dry wood being used as a main construction material, and

**CASE 2:** Comparing four different conditions i.e. no insulation on walls and roof and oven dry wood, polyurethane foam and fiberglass as insulation for the roof and walls respectively.

For this, a building with a volume of 46.22m$^3$ is considered. The area of the four walls and the roof are taken as 8.832m$^2$, 12.082m$^2$, 14.097m$^2$, 12.082 m$^2$ and 12.735m$^2$ respectively. The net floor area is similar to the roof area. The simulation is done for thermal comfort of 23°C. The weather is for a location at Shri Mata
Vaishno Devi University located in the state of Jammu & Kashmir, India with the latitude as 32.54 °N and longitude as 74.95 °E. The outdoor temperature and solar intensity is measured for a typical day in July 2014 for every hour, starting from 8:00 a.m. till 06:00 p.m., shown in Table 3.1. The data for outside temperature and solar radiation is measured using digital temperature indicator and pyranometer respectively. The digital temperature indicator uses a thermocouple as sensing element for precise observations with regard to temperature. The pyranometer used for measurement of solar radiation is a KIPP ZONEN SP Lite pyranometer with a sensitivity of 74 µV/Wm$^2$. The material choices for the construction are relevant to the location.

The standard construction material consisting of brick for the walls, reinforced concrete for the roof and stones for the floor are used. The brick walls are covered with sand/cement plaster on both the sides, contributing to thickness of 0.2286 m. This is followed by a variation of insulation material of 0.05 m thickness inside the building. The Oven Dry Wood, Polyurethane Foam and Fibre Glass are used as insulation and are having thermal conductivity of 0.0769, 0.03 and 0.04 respectively. Based on standard construction material and their physical properties, typical over all heat transfer coefficient values have been calculated and are shown in Table 3.2.

A MATLAB version R2012b was used to generate the code and the required graphical plots. The system has been analysed for the cases as mentioned above.
Table 3.1: Temperature and Incident radiation on a typical day of July 2014 (Latitude 32.54 °N and Longitude 74.95 °E)

<table>
<thead>
<tr>
<th>Time</th>
<th>Temperature (°C)</th>
<th>Solar Radiation (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.M.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:00</td>
<td>31</td>
<td>200</td>
</tr>
<tr>
<td>9:00</td>
<td>32.6</td>
<td>575</td>
</tr>
<tr>
<td>10:00</td>
<td>34</td>
<td>730</td>
</tr>
<tr>
<td>11:00</td>
<td>34.4</td>
<td>876</td>
</tr>
<tr>
<td>P.M.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12:00</td>
<td>34.8</td>
<td>810</td>
</tr>
<tr>
<td>1:00</td>
<td>34.3</td>
<td>600</td>
</tr>
<tr>
<td>2:00</td>
<td>35.5</td>
<td>780</td>
</tr>
<tr>
<td>3:00</td>
<td>36.4</td>
<td>650</td>
</tr>
<tr>
<td>4:00</td>
<td>36.6</td>
<td>430</td>
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<tr>
<td>5:00</td>
<td>33</td>
<td>140</td>
</tr>
<tr>
<td>6:00</td>
<td>30</td>
<td>110</td>
</tr>
</tbody>
</table>

Table 3.2: Type of Insulation, Construction Type and U Value of the material

<table>
<thead>
<tr>
<th>Type</th>
<th>Material</th>
<th>Calculated U Values (Wm⁻² K)</th>
</tr>
</thead>
</table>
| Wood used as Insulation| Plaster + Brick + Plaster + Wooden Insulation | Wall = 1.578  
Roof = 3.684 |
| Wood as Construction Material | Wood | Wall = 1.0253  
Roof = 1.676 |

3.1 TRANSIENT ANALYSIS OF RESIDENTIAL HEATING SYSTEM USING HELIO THERMIC PROCESS

All the researches are pointing towards the proper utilization of renewable energy because of exponential energy consumption (in buildings) and scarcity of
conventional energy sources. Space heating hence becomes an essential feature of building which ensures thermal comfort of inhabitants. There are many places where electricity distribution is not wholesome and/or is not present. These are particularly those regions which are far flung and beyond normal reach. As, transportation facility is also scarce, inhabitants living conditions become more adverse. Winters make conditions more adverse as everything is badly impacted. Owing to such facts a condition was exclusively chosen for the locations where the people are locked up in their shelters for long winter months as the adverse climatic conditions in these locations prove to be the lethal. Attempts to facilitate comfortable living in such locations and to take care of the availability of hot water so that it can be used to ensure comfortable living of dwellers is investigated. The simulation for checking for feasibility to use solar radiations to get hot water was carried out. The problem solving incorporated the heliothermal application solar thermal collector.

The presented study is an effort to introduce solar energy as a tool for space heating, considering two different conditions viz.

**CASE 1:** Ethylene Glycol was used as a liquid which was heated up with the solar collector having an area of 2 m$^2$. This heated liquid exchanged heat with the water in heat exchanger which was load liquid with starting temperature of 65°C. To maintain simplicity of problem we have studied the whole of system considering an assumption that liquid in circuit are not replenished at any point of time. To get a better understanding of problem further we only simulated the problem for a time period of ten hours beginning from 08:00 a.m. to 06:00 p.m. The schematic of problem is as shown in Fig. 3.1.
A pump sends in the absorbent fluid to solar collector so that it can get heated up. This fluid in turn after getting heated up in the solar collector moves on to the heat exchanger where it transfers the heat to the absorbate fluid. The absorbate fluid forms the working fluid of the second cycle.

![Schematic Circuit Diagram](image)

**Fig 3.1:** Schematic Circuit Diagram

The movement of this fluid inside the cycle is by virtue of the hydraulic energy imparted by another hydraulic pump. In this circuit water is stored inside a storage tank with variable losses. This storage tank can be assumed as an arrangement very similar to the heating arrangement that is incorporated inside the human shelters. Also, since the demand of chilled water varies directly to the sun’s position with respect to that time, tank can also be formulated as an element which is a part of some vapour absorption cycle which extracts the low grade thermal energy to provide refrigeration (primarily involved in chillers). There are plotters inside this software patch which can be linked to various elements. These plotters primarily collect information from different element and plot a temporal graph. The graph plots a number of variables of same graph opposite to time variables which give
relative information of different parameters. Also there are two sides (left and right) of vertical axis on which variables can be plotted. The main component of TRNSYS model is the solar collector. Additional components to the model include: pipe duct, hot water cylinder with 2 inlets and 2 outlets, Type 2b differential temperature controller, Type 114 variable speed pump, and Heat exchanger.

**CASE 2:** As an extension of previous case, district heating concept is utilized at a local level inside the building using solar energy, for New Delhi region in India. Different fluids are analyzed for a typical pipe material at different depths of their respective installation.

The system shown in Fig. 3.2 is simulated for climatic conditions of New Delhi, INDIA. The solar collector module having an area of 2 m² has been tested for the flow rate of 40 kg/hr. The intercept efficiency, efficiency slope and efficiency curvature are 0.80, 13 KJ/hr.m.K, and 0.05 KJ/hr.m.K. The module takes values of different radiations namely incident radiation, total horizontal radiation, and horizontal diffuse radiation. After that, it also requires ground reflectance, incidence angle and collector slope for internal numerical calculations. It receives temperature and flow-rate from source side pump and delivers heated fluid to a zero capacitance sensible heat exchanger (source side). The effectiveness of this constant effectiveness heat exchanger is assumed to be 0.6. Notably it doesn't uses overall heat transfer coefficient as in this version the efficiency is constant over the time-step. The maximum possible heat transfer is calculated on the basis of minimum capacity rate fluid and cold side and hot side inlet temperatures. The flow rate on both sides of heat exchanger is 10 kg/hr. The heated liquid received from solar
collector heats up water in secondary circuit. The heated water in secondary circuit passes through diverter. An added feature with the diverter enables it to bypass the circuit of installed pipes and go directly to mixer if required temperature is not reached. It checks the temperature of fluid coming out of heat exchanger and generates a value of 0 or 1 depending on the logic that the temperature is below or above 30 °C. The diverter splits the single inlet liquid according to specified value (between 0 & 1) into two liquid outlet streams. If the control signal is 1 then whole of water flows through the system of underground pipe structures and if control signal is 0 then it simply goes to mixer. The 10 m buried pipe has inner diameter of 0.027 m and outer diameter of 0.0334 m. The density, thermal conductivity, specific heat and viscosity of fluid is taken to be 1000 kg/m$^3$, 0.609 W/m K, 4.19 kJ/kg K and 0.00089 N.s/m$^2$ respectively. Similarly density and specific heat of the concrete are taken to be 2400 kg/m$^3$ and 0.92 kJ.K/kg. Both the circuits run forcibly with the help of pumps having same characteristics except the fact they provide hydraulic energy to different liquids. Both pumps have a rated flow rate of 10 kg/hr and of rated power 2684 kJ/hr.

To make a comparative and extensive study different parameters have been varied. The variations are listed below:

- The fluid in the primary circuit (Glycol, Ethyl Alcohol and Water)
- The pipe material for buried pipes is Aluminum (Al)
- The depth of the buried pipes.
For the schematics of circuits and detail description of individual components please refer Chapter 5 and section 5.2.

3.2 EVALUATION OF RENEWABLE ENERGY BASED VARYING COOLING CAPACITY ABSORPTION SYSTEM FOR BUILDING APPLICATION

Based on the literature reviewed analysis here evaluates influence of various operating parameters using the concept of energy and exergy in a single-effect ammonia-water absorption refrigeration system as a building conditioning system using Engineering Equation Solver (EES). The effect of the variation of cooling capacity on COP, exergy efficiency, exergy loss in different components and mass flow rate was analysed and discussed. The effect on COP and exergy efficiency with respect to the variation in generator temperature, evaporator temperature as well as absorber and condenser temperature has also been analysed and discussed. The effect of the variation in ambient temperature on the exergy loss in different components and exergy efficiency has also been discussed. The Chapter 6, proposes
a solar heat based system which is a single-effect ammonia water vapour absorption system with ammonia as a refrigerant and water as an absorbent as shown in the Fig 6.1.

The working of the single-effect system is same as described in reference (Anand et. al 2013) and is assumed to be based on certain assumptions as-

- The system operates at steady state conditions considering negligible heat loss through components.
- Solution leaving absorber and generator are assumed to be saturated in equilibrium conditions at their respective temperatures and concentrations.
- The refrigerant leaving condenser and evaporator are assumed to be saturated.
- Refrigerant vapour leaving generator is considered to be superheated.
- The reference enthalpy ($h_0$) and the entropy ($s_0$) used for calculating the exergy of the working fluid at an environmental temperature and pressure of $25^\circ C$ and 1 bar respectively.
- The mass flow rate of refrigerant at state points 2, 4, 5 & 6 is assumed to be same.
- The mass flow rate of weak solution at state points 3, 9 &10 is assumed to be same.
- The mass flow rate of strong solution at state points 1, 7 & 8 is assumed to be same.
- The pressure drop within the solution and refrigerant valves is negligible.
For carrying out the thermodynamic analysis the principles of mass conservation, first and second laws of thermodynamics are applied to each component of the system. The governing equations of mass and material balance for steady state operation of system are given in details in Chapter 6. The energy analysis is based on energy balance equations of various components for the different conditions as given in Table 6.1 based on various assumed parameters given in Table 6.2. The section 6.1.3 presents in details the exergy analysis for the same problem.

3.3 CFD BASED EVALUATION OF AN OFFICE SPACE FOR COMFORTABLE DWELLING

The literature review also suggests use of computational fluid dynamics as a tool for analyzing the building dwelling conditions. Based on literature reviewed presented study, considers a case of a build structure (two office rooms) at a typical location; 32° 56’ North latitude and 74° 57’ East longitude. The rooms are modeled using Pro-E modelling software and the analysis is carried using ANSYS Fluent package in ANSYS. The pictorial view, orthographic view and the mesh view of the build structure is shown in the Fig. 7.1, Fig. 7.2 and Fig. 7.3, respectively in Chapter 7.

Two rooms are considered which are situated adjacent to each other such that they share a common wall in-between. The room R1 is having a door and a window opening and the room R2 has only door as opening. The air can enter and exit from all the openings. In order to obtain more realistic flow pattern, it is important to simulate airflow around the building. Hence office building model is placed in a three-dimensional cubical box of adequate dimension as shown in
Fig. 7.3. The reported results are obtained by meshing the flow domain with an orthogonal mesh having 33,473,655 elements. The major assumptions considered in this analysis are

- Airflow is only due to wind effect.
- Window and door openings are the sole area for air exchange between indoor and outdoor.
- The room does not have any internal heat gain but is subjected to solar model for specified month.

The wind velocity and direction along with the other conditions are depicted in Table 7.2. The outdoor air temperature is as specified in Table 7.2. The roof and sidewalls are subjected to solar radiation with given direct and diffused radiations. These values have been measured for given location for 1200 hours and the 15th day of every specified month. The material used for entire solid surface is brick with properties as mentioned in Table 7.3.

Standard k-ε turbulence model is adopted to describe the turbulent transportation. Choice of k-ε turbulence model is a good compromise for realistic description of turbulence and computational efficiency (Fiala et al., 2003; Jones and Whittle 1992). Double precision segregated solver in FLUENT is used to solve flow domain. SIMPLE scheme is adopted and all the cases are iterated until all flow dependent variables meet a satisfactory convergence level of $10^{-4}$. The humidity distribution inside the rooms is also analysed. The Rosseland Radiation Model is adopted to include the effect of solar radiations on the structure. For purpose of iterating a real time condition, specific orientation of falling solar
radiation is selected. The weather data for chosen months of the year 2015 have
been considered for the evaluation of room condition with respect to occupant’s
satisfaction.

The model taken is an exact model described in Anand et al., (2014). In
this paper, variation of temperature in the interior of room due to application of
different coatings was experimentally determined. The temperature of the roof
was taken while substantiating the experimental data for three conditions,
i.e. bare roof, one coating, another coating. For validation of our procedure, we
took the case of bare roof and compared temperature values from data in the paper
with our simulation for very same points that were mentioned in the paper. This
model was utilized to predict the thermal comfort inside rooms for the entire year
(i.e. 2015) and indices such as the predicted mean vote (PMV) and Predicted
Percentage of Dissatisfied (PPD) were calculated. The results obtained have been
analysed which reflects the importance of such analysis in Chapter 7.