A Review on Performance Analysis of Passive Cooling and Ventilation System

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ABSTRACT
The energy demand for the residential and commercial building increases rapidly with the population. In the last two decade showed severe energy crisis found in developing countries especially during summer season. For hot climate countries like India, the application of cooling system plays important role. Passive cooling and active cooling are the two main type of cooling system. Active cooling requires power source to provide the desired effect whereas passive cooling includes the application of natural process along with passive technology without the use of power source. Passive cooling is used as low energy driven technique to remove undesired heat from the building to bring the comfort condition of occupant. There are numerous methods of passive cooling system but the present study discusses two most common passive cooling technique i.e., Earth Air Pipe Heat Exchanger (EAPHE) and Solar Chimney (SC). This paper aims to present the review on performance study and technological development of EAPHE and solar chimney at different climate condition.

Keywords: EAPHE, Energy, Evaporative Cooling Cavity, Passive Cooling, Solar Chimney, Thermal Energy

1. Introduction
Increasing energy demand in recent year because of fast economic growth of the thickly populated nations increases the utilization of sustainable energy sources and energy conservation methods. Shortage of conventional energy sources and high energy cost has caused the alternate methods for cooling and heating purpose of buildings. Power usage in buildings accounts 30% to 40% of global energy consumption. Passive cooling method is one of the many alternative methods of energy sources. Present study discusses performance of EAPHE and solar chimney as passive ventilation and cooling systems as well as performance of some integrated passive cooling systems [1].
Solar chimney mainly uses the technology which working on buoyancy principle, solar radiation passes through the glazed part of solar chimney part and walls of SC gets heated. Inside air temperature of the solar chimney (SC) channel rises and if the temperature difference is high enough, then the stack effect drives the air from interior of the building and the exhaust air is replaced by fresh air this increases ventilation rate inside room and reduces inside temperature of the room and the heat is carried out through convective cooling principle [2].

The schematic diagram of SC and human comfort range has been shown in Fig. 1 and 2.
The earth air pipe heat exchanger usage geothermal energy for the cooling effect inside the building. Mechanism of heat exchangers basically controls the temperature of the system by adding or extracting heat. Thermal energy can be exchanged from one medium to another medium only by means of temperature difference without using any power source. EAPHE works on the principle that the average underground temperature at certain depth i.e. 2-4m remains constant and it remains lower than the atmospheric temperature in summer and higher than the atmospheric temperature in winter. When atmospheric air is drawn through underground long pipes than outlet temperature of air reduces in summer and gets heated in winters. It uses underground soil as heat source.

Several researchers have studied the different parameters that affect the performance of solar chimney (SC). Computational Fluid Dynamics (CFD) analysis done by Chung et al. [3] shows optimum values of parameters which affects performance of SC. Researcher found that optimum air width gap ranges from 0.6m to 1.0m, length of chimney varies from 1.5m to 2m and induced air speed from .04m/s to 0.22m/s. Previous experimental study shows that Ventilation rate increases by 24% and it also shows that at air gap 10cm when the angle increases from 15 to 45° [4]. Alzaed et al. [5] shows by experimental study that air gap 5cm achieves better ventilation compared with 10cm air gap. Tongbai et al. shows by CFD model that at 6° channel expansion, flow ventilation increases by 90% [4]. Solar chimney gives better cooling performance when integrated with evaporative cooling cavity which maintains the air temperature of 27.31°C to 31.1°C and optimum evaporative cooling cavity length found 2m [6]. Figure shows the integrated system with acceptable range for ventilated building. The integrated solar chimney and Evaporative Cooling Cavity (ECC) and standard acceptable limit of building comfort at different climate conditions as shown in fig. 3 and fig. 4 [6, 7].

Mahdavinejad et al. [8] predict by simulation that at 45° tilt angle follows highest air flow in solar chimney. Amori et al. [23] establish CFD analysis and shows that solar chimney with absorber at middle of air gaps has the best thermal performance. Atmospheric temperature changes linearly with the solar irradiance. Hassanein et al. [9] shows by experimentally two to three chimney increases air flow rate to 13 to 33%. Bansal et al. [10] establish mathematical equation and found that 2.25m² area of solar collector was able to generate air flow rate between 140 to 330m³/hr at hot and dry condition. Solar chimney gives maximum performance at maximum irradiance 604W/m² [11]. Tyagi et al. shows by experimentally that parabolic solar collector enhances the system efficiency as an alternative energy [12, 13]. Glazing and absorber temperature increases as the angle of inclination of solar chimney decreases from 90 to 30° and flow rate of air reaches maximum for angle of inclination 60° to 70° [14].Performance study of solar chimney shows by experimentally that electrical consumption of an AC reduces by 10 to 20% [15].

Fig3: Integrated solar chimney and ECC  .  Fig4: Standard for naturally ventilated buildings.
2. Review of literature

Literature survey as per the previous work done by the researcher shows that solar chimney is the effective way to ventilate building, hence reduces inside temperature of the room and further reduces the cooling load of conventional air conditioning used for the cooling purpose. Numbers of study and experimental work has been done to enhance the performance of passive cooling and ventilation system.

2.1. Literature review on passive cooling system as solar chimney

Table 1 shows the review of literature on performance of solar chimney at different climate conditions. It also shows the different parameters studied to optimize the performance.

<table>
<thead>
<tr>
<th>S No</th>
<th>Ref. No</th>
<th>Name of the author</th>
<th>Title</th>
<th>Year</th>
<th>Methodology</th>
<th>Parameter Studied</th>
<th>Finding</th>
<th>Climate Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>Chung et al.</td>
<td>Effective solar chimney cross section ventilation performance in Malaysia terraced house</td>
<td>2014</td>
<td>Solar chimney optimization carried out by CFD.</td>
<td>1. Air width gap 2. Chimney Length 3. Air Velocity</td>
<td>1. Optimum width gap ranges from 0.6m to 1.0m, 2. Length from 1.5 to 2m 3. Induced air speed from 0.04m/s to 0.223m/s</td>
<td>Tropical climate with high temp. and humidity</td>
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<td>2</td>
<td>5</td>
<td>Alzaed et al.</td>
<td>Experimental study of solar chimney for ventilation in hot arid region</td>
<td>2014</td>
<td>Experimentally studied</td>
<td>Air Gap</td>
<td>Air gap 5cm achieves better ventilation compared with 10cm air gap.</td>
<td>Hot and dry condition</td>
</tr>
<tr>
<td>3</td>
<td>21</td>
<td>Ahmad et al.</td>
<td>Modeling and simulation of natural ventilation of building using solar chimney</td>
<td>2014</td>
<td>CFD software</td>
<td>1. Air width gap 2. Chimney Height</td>
<td>1. Optimum gap width is 0.4m. 2. Height 2m in majority of cases for different angles except 90 deg.</td>
<td>Hot and dry condition</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Tongbai et al.</td>
<td>Enhancement of roof solar chimney performance for building ventilation</td>
<td>2014</td>
<td>Study using CFD model</td>
<td>1. Angle of channel expansion 2. Air gap 3. Angle of Inclination 4. Height of Chimney</td>
<td>1. At 6° channel expansion flow rate increases by 24%. 2. Air flow rate increases up to 250% when air gap increased from 10 to 60cm. 3. At air gap 10cm when the angle increases from 15 to 45 deg. The ventilation increases by 90%. 4. Flow rate increases as height of the vertical chimney increases</td>
<td>Tropical climate with high temp. and humidity</td>
</tr>
<tr>
<td>Page</td>
<td>22</td>
<td>Tan et al.</td>
<td>Parameterization studies of solar chimneys in the tropics</td>
<td>2013</td>
<td>Experimental Study</td>
<td>1. Stack Height 2. Chimney Depth 3. Chimney width</td>
<td>1. Stack height increases the solar chimney outlet air temperature, 2. Optimum solar chimney depth is 0.5m, 3. Outlet air temperature decreases with increase width.</td>
<td>Tropical climate with high temp. and humidity</td>
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<td>5</td>
<td>8</td>
<td>Mahdavinejad et al.</td>
<td>The study on optimum tilt angle in solar chimney as a mechanical eco concept</td>
<td>2013</td>
<td>Simulation based study</td>
<td>Tilt Angle</td>
<td>45 degree tilt angle follow highest air flow.</td>
<td>Hot and dry condition</td>
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<td>6</td>
<td>23</td>
<td>Amori et al.</td>
<td>Numerical study of solar chimney with absorber at different location</td>
<td>2013</td>
<td>CFD Analysis</td>
<td>Different position of absorber</td>
<td>1. Solar chimney with absorber at middle of air gaps shows optimum performance. 2. The highest thermal efficiency with absorber at the back side during day hour.</td>
<td>Hot and dry condition</td>
</tr>
<tr>
<td>7</td>
<td>24</td>
<td>Kamal et al.</td>
<td>An overview of passive cooling techniques in buildings: Design concepts and architectural interventions</td>
<td>2012</td>
<td>Theoretical study</td>
<td>Methods of passive cooling studied</td>
<td>Studies shows the different methods of passive cooling system which reduces the cooling load in buildings.</td>
<td>Different climate condition</td>
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<tr>
<td>8</td>
<td>9</td>
<td>Hassanein et al.</td>
<td>Improvement of natural ventilation in building using multi solar chimneys at different direction</td>
<td>2012</td>
<td>Experimental work</td>
<td>Effect of no of chimney</td>
<td>Using two to three chimney increases air flow rate to 13 to 33%.</td>
<td>Tropical climate with high temp. and humidity</td>
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<tr>
<td>9</td>
<td>25</td>
<td>Mehani et al.</td>
<td>Passive cooling of building by using solar chimney</td>
<td>2012</td>
<td>Study solar chimney by CFD</td>
<td>Air gap width</td>
<td>Optimum air gap width was 0.2 to 0.3m for maximum ventilation.</td>
<td>Tropical climate with high temp. and humidity</td>
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<tr>
<td>10</td>
<td>10</td>
<td>Bansal et al.</td>
<td>Solar chimney for enhanced stack ventilation</td>
<td>2010</td>
<td>Mathematical model</td>
<td>Size of opening of solar chimney with varying discharge coefficient.</td>
<td>2.25m² area of solar collector was able to generate air flow rate between 140 to 330m³/hr at hot and dry condition</td>
<td>Hot and dry condition</td>
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<td>No.</td>
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<td>Author(s)</td>
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<td>12</td>
<td>26</td>
<td>Bassiouny et al.</td>
<td>Effect of solar chimney inclination angle on space flow pattern and ventilation rate</td>
<td>2009</td>
<td>Numerical simulation using ansys</td>
<td>Tropical climate with high temp. and humidity</td>
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<td>13</td>
<td>11</td>
<td>Arce et al.</td>
<td>Experimental study for ventilation on a solar chimney.</td>
<td>2009</td>
<td>Performance of solar chimney</td>
<td>Tropical climate with high temp. and humidity</td>
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<tr>
<td>14</td>
<td>33</td>
<td>Bassiouny et al.</td>
<td>an analytical and numerical study of solar chimney use for room natural ventilation</td>
<td>2008</td>
<td>Effect of chimney width</td>
<td>Tropical climate with high temp. and humidity</td>
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<td>15</td>
<td>14</td>
<td>Sakonidou et al.</td>
<td>Modeling of the optimum tilt of a solar chimney for maximum air flow</td>
<td>2008</td>
<td>Inclination of chimney</td>
<td>Hot and dry</td>
<td></td>
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<tr>
<td>16</td>
<td>34</td>
<td>Harris et al.</td>
<td>Solar chimney and building ventilation</td>
<td>2007</td>
<td>Effect of inclination angle</td>
<td>Hot and dry</td>
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<tr>
<td>17</td>
<td>27</td>
<td>Chungloo et al.</td>
<td>Application of passive cooling system in the hot and humid climate</td>
<td>2007</td>
<td>Experimental study</td>
<td>Tropical climate with high temp. and humidity</td>
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<td>18</td>
<td>35</td>
<td>Mathur et al</td>
<td>Performance of inclined solar roof chimney for natural ventilation</td>
<td>2006</td>
<td>Experimental study</td>
<td>Hot and dry</td>
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<td>19</td>
<td>36</td>
<td>Mathur et al</td>
<td>Experimental investigation on solar chimney for room ventilation</td>
<td>2006</td>
<td>Experimental investigation</td>
<td>High temp. and humidity</td>
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</table>
Liping et al. (2006) conducted an experimental investigation of a trombe wall system to enhance stack ventilation in buildings. They focused on mass flow rate, temperature field, and velocity field for trombe wall systems. The study revealed that mass flow rate is affected by solar radiation, and there is an optimum ratio of air gap width and chimney height, which is 1/10 to obtain maximum ventilation.

Bencheikh et al. (2004) developed a dynamic mathematical model to predict the performance of passive cooling systems by evaporative reflective roofs for hot dry climates. Their model included the concept of composited roof of concrete ceiling and flat aluminum plate, separated with an air space partially filled with rocks and small quantities of water. The efficiency of the system was studied, and it was found to lower indoor temperature by 3 to 4°C.

Khedari et al. (2003) performed a field study of solar chimney performance in air conditioned buildings. Their study showed that two passive cooling systems were used, with one maintaining 28°C in summer and 17°C in winter. These systems helped in reducing AC electrical consumption by 10-20% during the day and by 30% in the afternoon.

Raman et al. (2001) conducted an experimental study of passive solar systems for thermal comfort in composite climates. Two passive cooling systems were used, and the study found that the system maintained 28°C in summer and 17°C in winter. The efficiency experiment shows that it reduces the electrical consumption of an AC by 10-20%.

The methodology used in the study included CFD, Experimental, Simulation, Mathematica L Model, and Theoretical. The parameters studied included air width gap, chimney length, air velocity, angle of inclination, chimney depth, chimney width, solar irradiance, number of chimneys, and others. The figures show the percentage distribution of methodology used and parameters studied in the study.
2.2. Review of previous analytical and experimental studies of integrated approach

Performance of an integrated system with earth air pipe heat exchanger and solar chimney also shows the improved performance and ventilation effect. Researcher shows by mathematical model that indoor temperature maintains at 21.3°C to 25.1°C and humidity ratio maintains at an acceptable range of 50-78% [16].

EAPHE can be integrated with solar chimney to enhance the air flow velocity and performance of EAPHE. Amin et al. [18] establish a mathematical model for integrated solar chimney and EAPHE and found optimum performance at air gap of 0.2m, diameter of pipe 0.5m and pipe length 35m. Figure shows the integrated solar chimney and EAPHE[18]. Fig. 8 shows the integrated EAPHE and SC system and acceptable limit of comfort condition [7, 19, 20].

Maerefat et al. [19] also developed mathematical model for integrated EAPHE and SC and found that increased surface area increases ventilation rate and temperature reduction up to 18-20°C for optimum diameter 0.5m. EAPHE can be directly coupled with active room Air Conditioner (AC) to reduce the energy consumption by AC. Bansal et al. [38] coupled the earth air pipe heat exchanger with air cooled condenser of 1.5TR window AC and shows experimentally that electrical consumption reduced by 18% when 100% air from EAPHE is used to cool the condenser tube.

2.3: Review of literature

Table 2 shows the review of literature of the performance of the integrated passive cooling system at different climate conditions.
<table>
<thead>
<tr>
<th>S No</th>
<th>Ref. No.</th>
<th>Name of the author</th>
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<th>Finding</th>
<th>Climate Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32</td>
<td>Kumar et al.</td>
<td>Analysis of solar chimney with evaporative cooling cavity to improve indoor air quality</td>
<td>2015</td>
<td>Experimental study</td>
<td>1. Effect of air velocity on cooling effect. 2. Effects of different cooling pads</td>
<td>1. Saturation efficiency increases by 47% at 0.10 m/s. 2. Cellulose cooling pad gives higher efficiency compare to straw and coir. 3. SC-ECC is better for well insulated building.</td>
<td>Hot and dry</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Yuan et al.</td>
<td>A Review of Technological Development in Cooling System for Different Climate</td>
<td>2014</td>
<td>Review of different techniques</td>
<td>Combination of active and passive cooling system</td>
<td>Integrated system of active and passive system source significant result in saving energy</td>
<td>Hot and Humid</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>Li et al.</td>
<td>Performance of a coupled cooling system with earth to air heat exchanger and solar chimney.</td>
<td>2014</td>
<td>Mathematical model</td>
<td>Combined cooling effect and relative humidity</td>
<td>1. Integrated coupled system maintain an indoor air temperature 21.3°C to 25.1°C 2. Humidity ratio was maintained at a range of 50-78%.</td>
<td>Hot and dry</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>Haghghi et al.</td>
<td>Design guideline for application of earth to air heat exchanger coupled with solar chimney as a natural heating system.</td>
<td>2014</td>
<td>Experimental and mathematical modeling</td>
<td>Effect of no of buried pipe and solar chimney.</td>
<td>Numbers of solar chimney and pipe channels are dependent by outdoor condition and heating load of building.</td>
<td>Hot and dry</td>
</tr>
<tr>
<td>5</td>
<td>37</td>
<td>Miyazaki et al.</td>
<td>The cooling performance of a building integrated evaporative cooling system driven by solar energy.</td>
<td>2012</td>
<td>Simulation</td>
<td>Cooling load</td>
<td>System can reduce up to 10% of cooling load.</td>
<td>Hot and humid condition</td>
</tr>
<tr>
<td>6</td>
<td>17</td>
<td>Dokkar et al.</td>
<td>Passive Cooling of telecom shelter using solar chimney with earth –air heat exchanger</td>
<td>2012</td>
<td>CFD Analysis</td>
<td>1. Outlet temperature EHAE 2. Flow rate and velocity</td>
<td>Temperature in the middle of the shelter does not exceed 29 degree centigrade</td>
<td>Hot and dry</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>Poshiri et al.</td>
<td>Comparative survey on using two cooling systems, solar chimney earth to air heat exchanger and solar chimney evaporative cooling cavity.</td>
<td>2011</td>
<td>Experimental and mathematical modeling</td>
<td>Cooling effects</td>
<td>Result shows SC-EAPHE system is best choice for the building with poor insulation.</td>
<td>Hot and humid</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>Poshiri et al.</td>
<td>Feasibility study on using solar chimney and earth –to- air</td>
<td>2011</td>
<td>Experimental and mathematical</td>
<td>1. Air gap depth of SC 2. Diameter of pipe</td>
<td>Results shows that optimum size of air gap 0.2 m, diameter of pipe 0.5 m and length 35 m</td>
<td>Hot and dry</td>
</tr>
</tbody>
</table>
3. Result and discussion

The continuing increase of energy consumption of air conditioning, energy efficient cooling systems are needed to replace the current electrical air conditioners used in most commercial and residential buildings. An energy crisis in developing country like India raises the demand of passive cooling systems which runs without using power source. This paper review the performance analysis of passive cooling and integrated technology used to enhance the performance of cooling system. This paper also review the integrated SC and EAPHEsystem which are the most commonly used as a passive cooling system. Integrated SC and EAPHE system can replace the conventional AC system. It reduces the building energy load. A combination of passive and active cooling system has shown significant result in saving of energy and provides good thermal comfort without causing much pollution to the surroundings.

4. Conclusion

Because of growing demand of energy and increasing cost of electrical energy, it is required to reduce peak load as well save energy. Solar chimney and earth air pipe heat exchanger are the new approach to reduce the cooling load by means of passive ventilation and cooling which requires low energy to run the system. It was found that integrated system along with EAPHE gives more satisfactory results. If solar chimney can be used for optimum result, it reduces the electrical consumption by 10-20%. Solar chimney can be used at night by installing rotary turbine at the outlet of solar chimney to charge the battery. Performance of integrated SC-ECC system can be enhanced by increasing the evaporation rate of water and that can be achieved by adding some additives. It was found that EAPHE is the commonly used methods for cooling of heating purposes. Literature review shows that temperature drop up to 12.6°C can be achieved and energy consumption gets reduced by 18% when coupled with air cooled condenser of 1.5TR window AC. EAPHE outlet can be directly
connect to the AC suction to reduce the cooling load. Proposed future work has been identified where research is lacking as mentioned below:

- Use of CFD model to predict the outer temperature in winter of EAPHE system under unsteady condition shall be studied.
- Geothermal energy and thermal properties of soil shall be studied at different location.
- Theoretical model should be developed to predict the temperature of soil and effect of moisture content in the soil.
- Humidity control mechanism should be incorporated for winter and summer season.
- Work should be done to increase the heat transfer rate of buried pipe to increase the cooling effect.
- Mathematical model should be developed to predict no of buried pipe required for the desired effect.
- Effect of density of air and moisture on cooling effect and heat transfer rate should be studied.
- Counter flow pipe shall be used for EAPHE to enhance the performance.

References