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# Heating/Cooling Techniques used in Green Buildings: A Review

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**ABSTRACT: Today World is facing with the problem of energy conservation. Worldwide energy problems are future availability of fossil fuels, climate change, and energy conservation, technological and economical feasibility of renewable energy. They force us to develop renewable energy policies, search latest techniques and adopt them. Building heating/cooling consumes significant amount of energy. It must be conserved to save the fossil fuels and control the global warming, ozone layer depletion, health problems, emission of green house gases (GHGs), etc. This paper reviews and critically analyzes various active, passive and hybrid heating/cooling techniques and their role in energy conservation criterion.**

**Keywords:** Natural ventilation, Energy conservation, hybrid ventilation techniques.

**Abbreviations:** GHGs, greenhouse gases; PCM, phase changing material; SC, solar chimney; GCHE, ground coupled heat exchanger; EAHE, earth air heat exchanger; GSHP, ground source heat pump; PV, photo voltaic; HVAC, heating ventilation and air conditioning; AC, air conditioner; PBP, payback period.

## I. INTRODUCTION

Green building uses less energy, water, natural resources and generates less waste. It creates healthier environment for people living inside the building. Design aspect covers site planning, envelope design, indoor thermal, visual, comfort and air quality. It uses ecological sustainable, renewable and ability to recycle materials.

In green building, space heating/cooling, ventilation and air-conditioning are the main areas where considerable amount of energy can be saved. Green building control strategies use various concepts of natural heating/cooling, ventilation and air-conditioning [33]. Heating/cooling of building, air conditioning and ventilation are complimentary to each other and maintain freshness, temperature, comfort level. Air conditioning and ventilation are the main pillar of building heating/cooling process. Efficient ventilation helps to increase efficiency, energy conservation and cure heath problems. Ventilation process maintains air quality, supplies fresh air to a space and replaces stale air. It removes bacteria, smoke, moisture, dirty things. Air infiltration should be properly controlled to conserve energy. Process of heating, cooling, ventilation, air conditioning can be achieved by passive/natural or active/artificial or combination of them. In natural the air flows due to natural wind and buoyancy. It conserves the energy and suitable only for day time. It can't be used during night time and in existence of pollutants. Active/mechanical/artificial ventilation is good for day and night times both for heating/cooling.

It provides guaranteed performance, controlled noise and safe environment. But due to limited stock of fossil fuel and climate change problems, world scenario is focusing towards natural heating, cooling, ventilation and air conditioning through renewable technologies to meet out future energy demand and emission targets.

## II. HEATING/COOLING SYSTEMS

Heating/cooling techniques can be described as passive and active systems. There are many factors which play key role in influencing the air current, they are speed of wind, buoyancy (stack) pressure, effective area of multiple openings, terrain features (local), seasonal and daily effects on wind characteristics i.e. variation on pressure, speed, direction, etc.

### *A. Passive systems*

Passive systems are based on renewable energy sources. Types of passive systems are natural/induced ventilation, solar wall (Trombe wall), solar chimney, wind towers, phase changing material (PCM), thermal insulation etc.

**Natural/Induced Ventilation Techniques.** Induced ventilation takes place due to difference in air temperature.

Hot air goes up and then through chimney/openings escapes out in the environment. Cool air comes down and to fill the empty space cool air comes inside from lower height openings due to its higher weight than hot air, as shown in Fig. 1.

**Trombe Wall.** Trombe wall is also known as solar wall. It is south facing thin and glazed wall [18]. This wall takes solar heat and then ventilates the air. It can be used in day and night both for all purpose *i.e.* winter heating and summer cooling. In day hours vents are open to ventilate the air and during night time vents are closed to maintain the room temperature, as shown in Fig. 2.

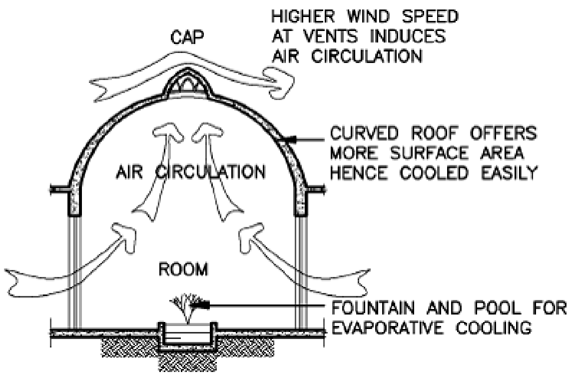



**Fig. 1.** Induced ventilation.

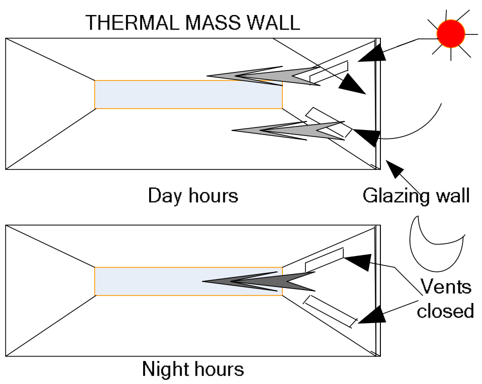



**Fig. 2.** Day and night operation of trombe wall.

**Solar Chimney (SC).** It is old technology, work under principle of stack effect (temperature difference), as shown in Fig. 3. Key factor are solar radiation, air flow rates, solar absorbing plate, inclination angle and gap, cross sectional area of inlet and out let vent, which affect the ventilation rate [18].

In day time it absorbs solar energy but during night time requires heat storage mass i.e. PCMs. SC can be engaged in various applications i.e. ventilation, power generation, food drying [13,19,24].

**Wind Tower.** It is preferred for cooling purposes in windy areas, dry climate and absence of pollutants, as shown in Fig. 4. Earlier it was known as wind catcher, installed at top of the building with the multiple directional openings to capture the more wind from all directions, as shown in Fig. 4. It is able to work in both day and night for heating/cooling. During night hours cool air takes heat from warm walls then rise due to buoyancy effect [18].

**PCMs.** PCM is gaining popularity for storing thermal energy. It has high energy storage density. PCMs change their phase according to variation in temperature. PCM can be explained simply by taking example of water. It changes its phase with change in temperature. But it has a major drawback that it can't be sustained for long. Mainly latent heat of the materials is the key factor for increasing/decreasing the duration of storing heat [43].

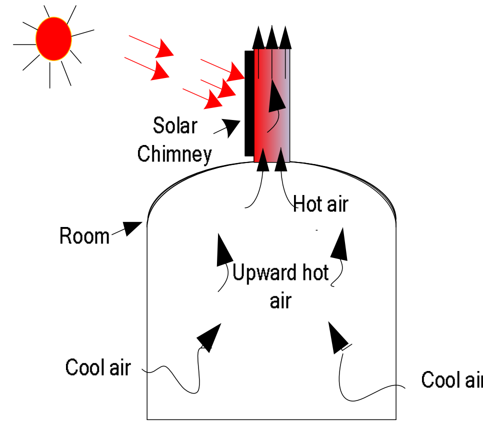



**Fig. 3.** Solar chimney.

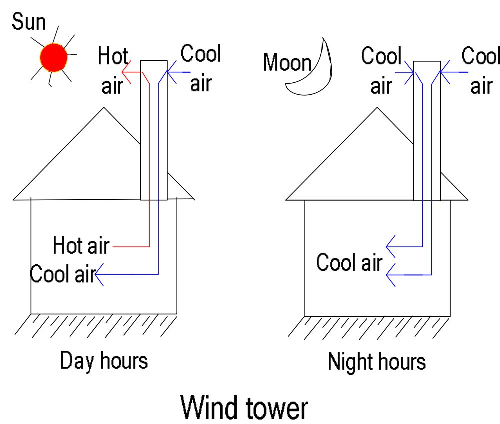



**Fig. 4.** Wind tower (day and night time).

**Thermal insulations.** Application of thermal insulations in space heating/cooling is increasing exponentially. It develops an artificial envelope around the building. It prevents heat/cold ingress from surroundings. It keeps at least 10$^{o}$C temperature difference in comparison to without applying thermal insulation, shown in Fig. 5. It keeps required temperature for longer periods and human comfort.

Proper awareness of loads (i.e. envelope, occupancy, equipment, lighting and outside air total load) helps in energy conservation. Envelope load plays important role in space heating/cooling [22, 42]. High envelope load and reduced envelope load due to proper use of hybrid heating/cooling system, thermal insulation and building orientation etc., subsequently it's impact on other loads, as example is shown in Fig. 6 (a), (b) respectively.

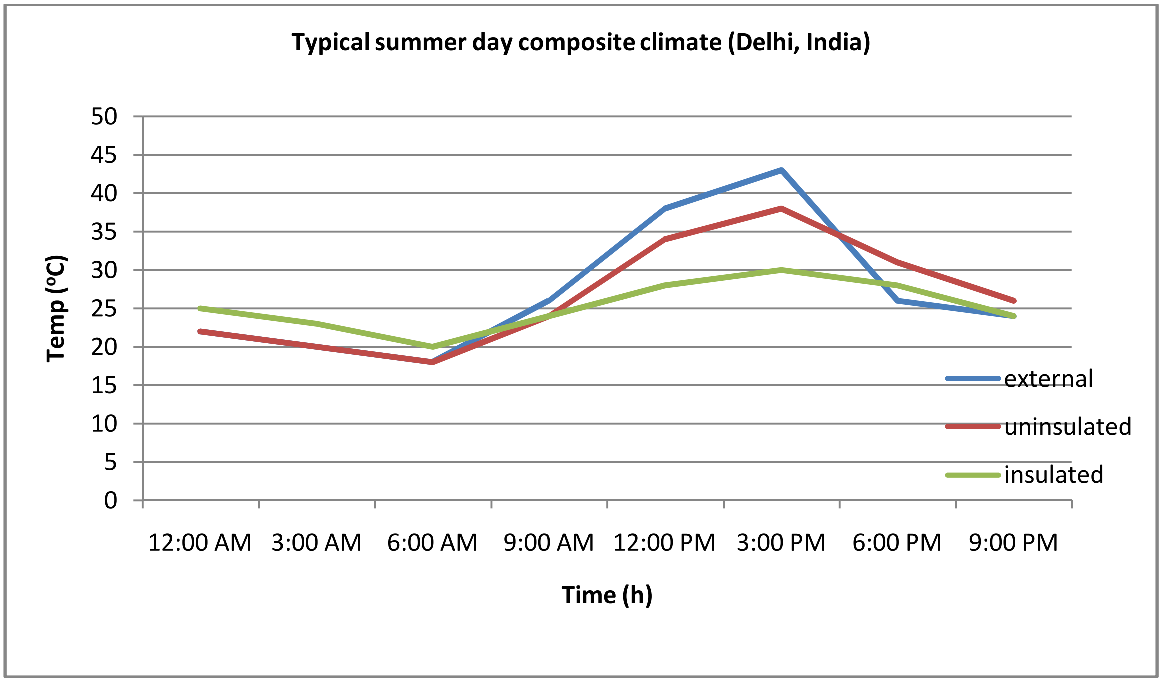
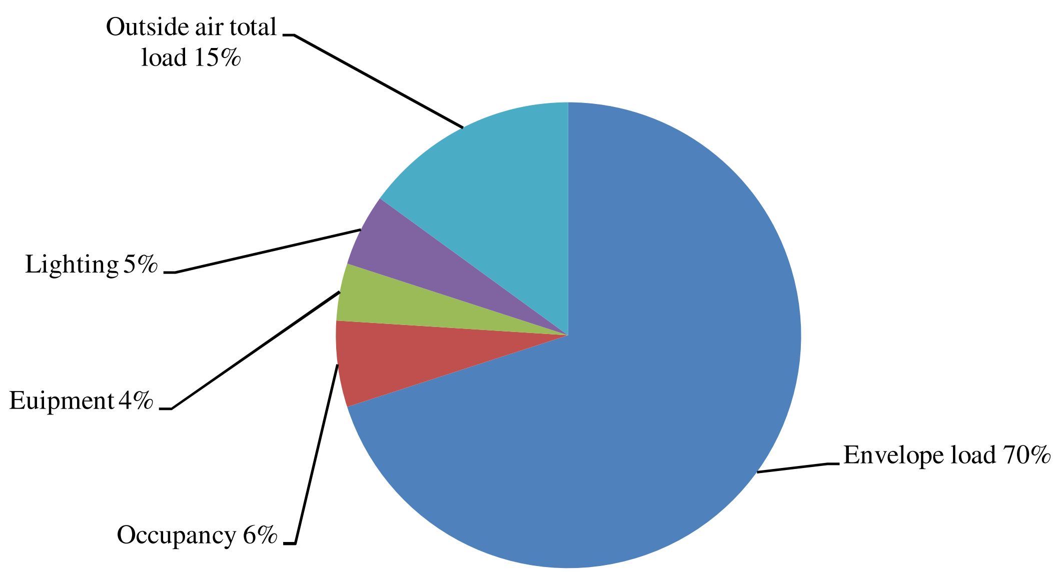
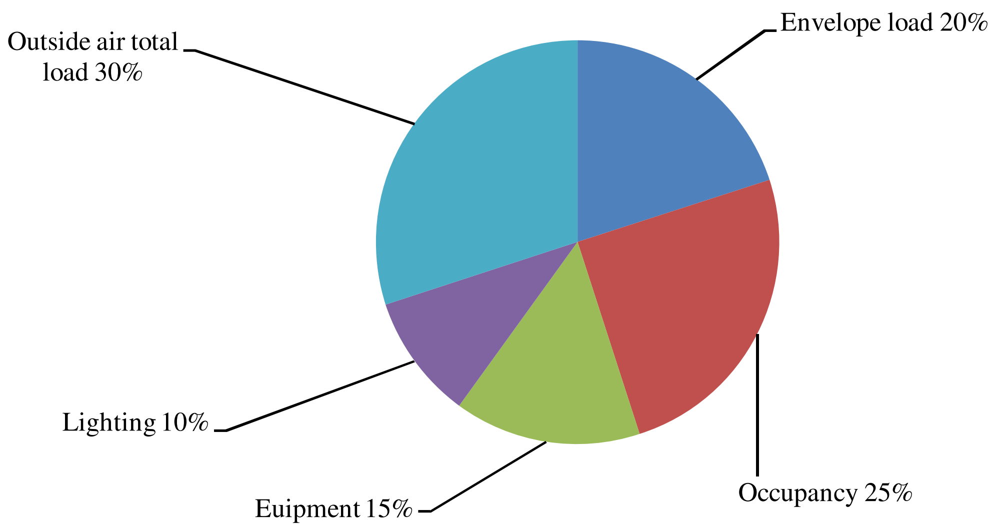



**Fig. 5.** Impact roof and wall insulation with 50 mm insulation (Source: Owens Corning).




(a)




(b)

**Fig. 6.** Load distribution (a) original and (b) impact of implementation of proper load management systems.

*B. Active systems*

Active systems consume fossil fuels (i.e. air heater, HVAC) or both i.e. renewable and fossil fuels like ground coupled heat exchanger (GCHE) systems. It is popular, energy efficient and environment friendly. GCHE systems can be classified as earth air heat exchanger (EAHE) system and ground source heat pump (GSHP) systems.

**EAHE System.** It consumes electricity to blow the air and use earth as heat sink for heating/cooling, as shown in Fig. 7. EAHE system is also called as earth tubes, earth air pipe, air-to-soil heat exchanger, earth channels, earth canals, earth air tunnel systems, ground tube heat exchanger, subsoil heat exchangers, thermal labyrinths and underground air pipes. Earth temperature remains constant throughout the year to the annual average temperature approximately 5 meter deep. This constant temperature characteristic of earth is utilized for heating/cooling air that passes through buried pipe [4,6,7]. EAHE system is preferred to those areas where ground temperature fluctuates frequently and in high level. Key factors are air velocity, depth and length of buried pipes, thermal diffusivity of soil, etc.

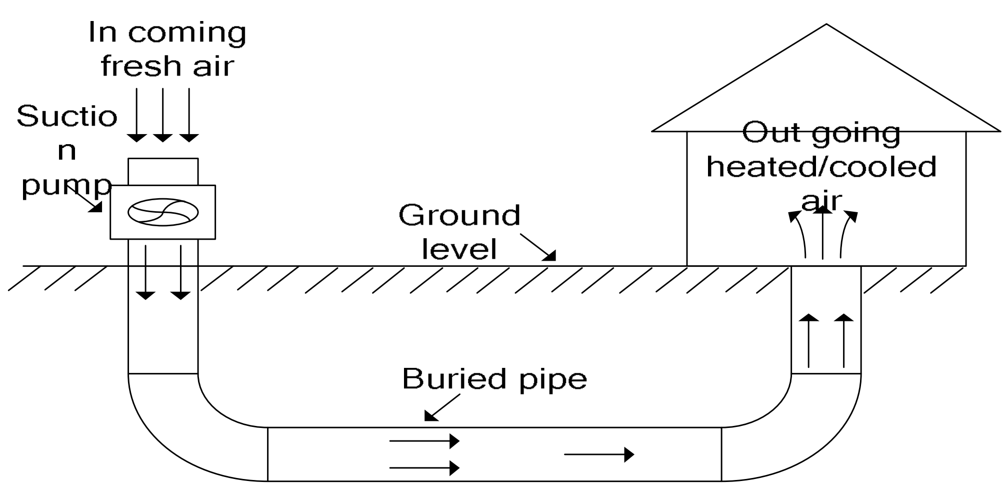



**Fig. 7.** Earth Air Pipe System.

**GSHP systems.** Concept of GSHP system was introduced in 1852 but got the viable recognition in 1960-70s. It follows the same principle as refrigerator. It takes electrical power to circulate the fluid through loop for utilizing constant earth's temperature and exchanging heat. It is suitable for all seasons. It is popularly used in various applications in many developed countries i.e. United States, Canada, Switzerland, Sweden, Austria, Germany, etc. It can be further classified as regular and direct heat exchange geothermal system. Comparative study between passive and active systems is presented in Table 1.

**Table 1: Comparative study between passive and active systems.**

| Parameters | Passive systems | Active systems |
|---|---|---|
| Cost | Low | High |
| Fuel | Renewable | Fossil or renewable and fossil both |
| Applicability | Restricted | in all climatic conditions, day and night both |
| Efficiency | Low | high |
| Life | High | moderate |
| Maintenance | Low | moderate |
| Sustainability | High | low |
| Comfertability | Low | high |
| Payback Period | Moderate | low |
| $CO_2$ emission | Almost nil | moderate |

It is concluded from Table 1 that alone passive or active systems are not appropriate and sustainable due to increasing energy demand trend in space heating/cooling. It forces us to adopt suitable hybrid systems according to tailor made situations.

## III. LATEST TRENDS IN SPACE HEATING/COOLING: HYBRID SYSTEMS

To promote renewable technology, incremental adoption of hybrid system i.e. combination of GCHEs with passive systems play important role towards sustainable development, as shown in Fig. 8.

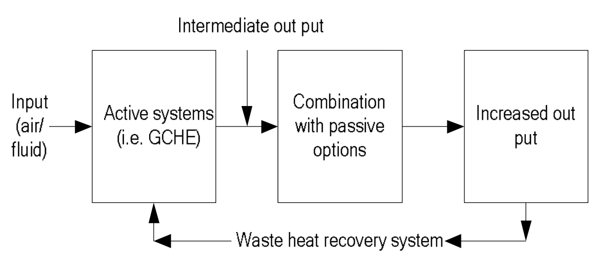



**Fig. 8.** Concept of hybrid systems.

GCHE systems give higher efficiency with some combinations i.e. evaporative cooling, solar PV, SC, PCM, conventional heating ventilation air conditioning (HVAC), etc [8,9,11,15, 16-17, 20-21, 25-28, 30, 34, 36, 39].

Bansal *et al.* [5] integrated EAHE system with evaporative cooler. It was concluded that hybrid system is economically feasible option, for obtaining desired temperature. EAHE pipe length could be reduced up to 93.5% compared to alone EAHE system.

Khalajzadeh *et al.* [15] tested ground heat exchanger system with evaporative cooling system at Tehran, Iran. It was observed that cooling power of tested system was higher than conventional. Momin *et al.* [21] also proved that ground heat exchanger with evaporative cooling at Pune, India that conventional air conditioning system could be replaced by integrated geothermal air conditioning system. It was observed that COP could be significantly increased i.e. 2.2855 to 4.1415.

Sahay *et al.* [38] tested a hybrid system of EAHE and solar PV panel in Bhopal, India. Efficiency of solar PV panel fallen down 0.5% for increase of 1$^{o}$C pannel temperature. It was concluded that EAHE system was efficient and cost effective for PV panel cooling.

Rodrigues *et al.* [12] developed a hybrid system of EAHE and PCM. Hybrid system enhanced cooling effect up to 47% compared to conventional air conditioning system. It was concluded that combined output of EAHE and PCM system was appreciable and it could be the alternative option of conventional air-conditioning.

Misra *et al.* [26] developed an experimental setup of EAHE system plus conventional air conditioner (AC) at Ajmer, India. Test had four modes of operation, they were as follows,

- In mode-I all 100% conditioned air through AC supplied to the experiment room.
- In mode- II AC and EAHE system both supplied their full conditioned air to room.
- In mode -III firstly EAHE system supplied their full air to AC's condenser coils to cool them and then AC supplied their full conditioned air to room.
- In mode-IV firstly EAHE system supplied their half (50%) cooled air to AC's condenser coils and remaining half (50%) air directly to room.

**Table 2: Comparative study of experimental results.**

| Modes | Power consumption as compared to mode-I (i.e. base mode) |
|---|---|
| II | 6% less |
| III | 18.1% less |
| IV | 16% higher |

AC supplied full conditioned air to room. Compared result with mode-I has been shown in Table 2. After analyzing all results, it was concluded that appropriate mode of operation was mode-III and hybrid systems would be the proper technology for sustainable growth.

Haghighi *et al.* [16] tested the combined system of EAHE and solar chimney (SC). It was concluded that EAHE with the diameter and length of 0.5 and 25.0 m respectively and SC with the air gap and outlet sizes of 0.2 m gave the enhanced performance.

Poshtiri *et al.* [30] developed a mathematical model to optimize the combination of SC and EAHE system. It was concluded that air gap depth up to 0.2 m was significant and after that room temperature maintained constant. Design of EAHE with diameter 0.5 m was optimum.

Tavakolinia [39] developed an experimental setup of wind-catcher integrated with a solar chimney and EAHE system at Los Angeles, California. It was concluded that the hybrid system reduced the energy consumption, noise and emission level compared to convention air conditioning system.

Benhammou *et al.* [10] experimented hybrid system of EAHE with wind tower for summer cooling in hot and arid regions of Algeria. It was found that ambient air after passing through the hybrid system was colder than the conventional cooling tower.

Allaerts *et al.* [1] tested the hybrid GSHP system with renewable sources or active regeneration system in Flanders, Belgium. It was concluded that significant 47% borefield size was reduced than alone GSHP system. Combining with renewable sources or active regeneration system made it economical feasible, otherwise high initial costs of borehole drilling limits their application.

McKenna *et al.* [28] tested and simulated the integrated system of GSHP and PCM using TRNSYS. It was found higher efficiency of integrated system than unity system, and then simple models for Mediterranean climate were developed using validated models. Jones *et al.* [17] validated the same concept using ENERGYPLUS. García-Alonso *et al.* [15] studied on feasibility of integration of GSHP with PCM to meet out the domestic water heating and heating energy requirement for single family house located in a European continental climate. It was concluded that 37% energy could be saved in comparison to water used as heat storing medium. Gao *et al.* [14] concluded that GSHP and underground thermal energy storage would gain marvelous market in China and other developing countries like developed countries i.e. Europe, North America, etc. Energy storage systems made possible the efficient utilization of renewable energy sources and energy conservation [31]. Moreno *et al.* [29] studied and concluded that combination of GSHP and PCM could be used for heat recovery, defrosting in air-conditioners and shifting the load demand, effectively.

Sayyadi *et al.* [32] presented a new method for optimization of a cooling tower-assisted GSHP. Results reflected that the product cost of all systems and interest rate were directly linked. Thermodynamic optimization was economically feasible, only when the operating time in cooling mode was sufficient long and/or the electricity price was high. Cui *et al.* [12] presented the simulated model using TRNSYS 16 for the performance of hybrid GSHP with cooling tower. It was found that hybrid GSHP system with cooling tower was the suitable to deal with the thermal imbalance.

Kamal *et al.* [23] reviewed various research papers on solar assisted heat pumps, concluded that hybrid systems could reduce 8-15% electrical power and sustainable. Badescu [3] developed a model for heat pump with solar collector. It was concluded that hybrid system reduced 8% electrical power, compared to only heat pump. Wang *et al.* [41] tested and concluded that performance of solar ground coupled heat pump mainly affected by solar radiation, water tank volume and area of the solar collectors. The economic analysis techniques i.e. simple payback period, discounted payback period, net present value and internal rate of return validate that proposed hybrid arrangements are economically viable [35].

It is concluded from table that hybrid systems are sustainable, efficient, economical feasible. It is suitable for the efficient utilization of renewable resources. It is precious to solve the difficulty of the inequity between cooling load and heating load in some excessive hot or cold climate areas.

**Table 3: Summary of hybrid systems literature review.**

| Parameters | Compared to unity system | Remarks |
|---|---|---|
| cost | high | It can be reduced if implemented during building planning/construction stage. |
| life | moderate | Life can be increased by proper maintenance. |
| hybridization | EAHE/GSHP + passive systems | It's a permutation and combination according to situation's demand. |
| efficiency | High [2] | Efficiency depends on appropriate product-mix, climatic conditions, etc. |
| $CO_2$ emission | High [37] | $CO_2$ mitigation is the world priority agenda. |
| Energy savings | High [40] | Saves the fossil fuels and environment. |
| payback period | Low [1] | Hybrid systems are economic feasible. |

Energy efficiency in space heating/cooling can be achieved by minimizing the heat ingress or heat loss, recovering and recycling the energy losses wherever possible and feasible, using automation to meet the set points under dynamic internal loads and weather pattern. Proper awareness of loads (i.e. envelope, occupancy, equipment, lighting and outside air total load) and energy consumption help in selection of appropriate hybrid systems.

## IV. CONCLUSION

Hybrid heating/cooling systems are efficient, environmental friendly, economical feasible and suitable for sustainable development. They promote use of renewable techniques and able to conserve significant amount of energy i.e. 10-30% of total consumption for space heating/cooling. Literature review presented that various combinations of passive and active technologies i.e. GCHE systems, evaporative cooler, conventional HVAC, solar chimney, solar PV, PCM, wind tower, etc. were the better option than adopting unity system. 93.5% reduction in length of EAHE pipe, 100% increase in the COP could be achieved by adding evaporative cooling system. EAHE system was the cost effective cooling system for solar PV panel. Use of PCM enhanced the cooling effectiveness of EAHE system as compared to conventional system by 47%. Power consumption of conventional air conditioner system could be reduced by 18.1% through cooled air supplied from EAHE system. 47% bore field size of an GSHP system could be reduced with by adding renewable sources or active regeneration system. PCM was 37% effective than water in house and water heating. Solar assisted heat pump could reduce 8-15% power consumption.

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