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Advancements in the passive design Strategies for Building Daylighting, Space ventilation and thermal Conditioning: A Review

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Abstract : *The energy is the basic need in present scenario due increasing the industrialization and the living standard of the humans. The application of energy in ventilation and space conditioning of buildings are the major contributors of energy utilizations. The renewable energy options like solar day lighting via light pipes, ventilation and space conditioning via solar chimney, trombe wall, EATHE, BHE and their integrated approaches can be used. Their performance can also being improved with the integration of evaporative cooling and adsorption cooling approaches. The required ACH (5-9) can be achieved alongwith the room temperature of 13°C to 26 °C can be easily generated with the integrated approaches. By these approaches we can saved the commercial energy utilization and saved the environmental degradation.*

Keywords: *Light pipes, Earth sir tunnel heat exchanger, Borehole heat exchanger, integrated approaches, solar chimney Trombe wall etc.*

1. INTRODUCTION :

The largest expansion strategy for renewable energy exists right now. India was the third largest market worldwide and the second largest market in Asia for new solar PV capacity. At the COP26, the nation increased its goal to 500 GW of non-fossil fuel-based energy by 2030. This has been a major Panchamrit promise. In terms of overall installations, it came in at number four (60.4 GW), passing Germany (59.2 GW) for the first time. As of February 2023, India's installed renewable energy capacity—which includes large hydro—was over 174.53 Giga Watts, or over 42.5% of the nation's total capacity, up 396% over the previous 8.5 years. In 2022, India experienced the biggest year over year growth in the addition of renewable energy, at 9.83%. As of February 2023, the installed solar energy capacity has grown by a factor of 24.4 during the previous nine years, reaching 63.3 GW. Since 2014, the installed capacity for renewable energy (including large hydro) has increased by over 128% [1]

India presently has 168.96 GW of total renewable energy capacity (as of February 28, 2023), with roughly 82 GW of that capacity being implemented at various phases and over 41 GW being in the tendering stage. This includes 42.02 GW of wind energy, 64.38 GW of solar energy, 51.79 GW of hydropower, and 10.77 GW of bioenergy [2].

The environment, energy use, and human health are all significantly impacted by building construction and infrastructure development operations. The AEC sector contributes significantly to rising pollution and resource depletion on a global scale [3] . According to a recent study by Architecture 2030, "The built environment generates 40% of annual global greenhouse emissions." Building activities account for 27% of those total emissions annually, while building and infrastructure materials and construction (often referred to as embedded carbon) account for an additional 13% of those emissions [4]. Such a concerning statistic shows the urgent need for architects and engineers to develop design solutions beyond active design techniques with low environmental impact.

Resources are few in developing nations, and it is vital to talk about how this is limiting social and economic growth. On the other hand, as industry and infrastructure expand quickly, there is a rise in energy demand. Comparing the building industry to the industrial, agricultural, and transportation sectors, the building sector (commercial and residential) consumes the most energy. Building energy use is mostly accounted for by the heating and cooling load, which rises as India's infrastructure is built up vertically. Aside from 33% industrial and 28% transportation, commercial and residential buildings consume the most energy [5]. Lighting, heating, cooling, cooking, ventilation, washing, computers, refrigerators, and other appliances all use energy, but space heating and cooling and lighting account for the majority of energy use. Ventilation equipment contributes 6% more to end use in the USA than it does in India [6]. In order to heat buildings in the winter, thermal energy is frequently applied. In different seasons, such as peak winter and peak summer, the ground source can be used for both space heating and cooling, where the highest temperature difference between the peak ambient temperature and the annual average sol-air temperature on the earth's surface can be used to determine the maximal heating and cooling potential. To reduce the usage of conventional energy and fuel, thermal devices based on renewable energy may be developed. The use of energy-efficient passive heating and cooling systems, such as solar chimneys, earth air tunnels, and borehole heat exchangers, is crucial to increasing sustainability, reducing energy consumption, and enhancing environmental awareness.

About two thirds of the world's greenhouse gas emissions are related to the energy sector [7]. The earth's surface temperature is rising as a result of an increase in the quantity of greenhouse gases in the atmosphere, such as CO2, SO2, CH4, CFCs, and NOx [8]. In the last 200 years, CO2 levels have risen by 31%, while methane gas, which damages the ozone layer, has increased by more than twice that amount.

The second-largest energy consumer in the construction industry is lighting. In India, it makes up 20% of all the electricity used [9]. One of the most popular solutions is daylight, which should be used as much as possible to reduce the energy used for artificial lighting in structures. There is now a need for daylight data for vertical surfaces so that sophisticated daylight systems, including light pipes, light guides, energy-efficient windows, and glass walls, may be tuned for the best possible use of the sunshine [10]. While a daylighting system may have some drawbacks, it can also have benefits in terms of energy savings, a better interior atmosphere for users, and improved job performance in office buildings [11, 12]. The amount of light required, as well as the climate and architectural style, should be taken into consideration while choosing and positioning windows and skylights [13]. India has set goals to reach net-zero carbon emissions by 2070, achieve cumulative renewable energy installations of 50% by 2030, and lower the carbon intensity of the country's economy by less than 45% by the end of the decade. By 2030, India could experience a market growth of up to $80 billion due to low-carbon technologies [14].

According to a review of the literature on energy demand and supply, the building industry is the largest consumer of energy (39%), followed by the industrial sector (33%), and the transportation sector (28%). Approximately 45% of the energy used by the building sector is used for ventilation and space conditioning (heating and cooling). There is a vide scope area where passive ventilation and climate control can be used. Small energy savings in construction can contribute to environmental protection. The paper is deals with the technical review on Utilization of solar energy in both active and passive design Strategies for Building Daylighting, Space ventilation and thermal Conditioning.

2. Solar daylight and Passive approaches for ventilation and space conditioning :

The largest energy consumer, excluding the industrial and transportation sectors, is the housing sector. Therefore, compared to the electric power industry, the advantages to human health from reductions in energy use in the housing sector are many times greater. The expense of lowering greenhouse gas emissions was expected to be significantly outweighed by the economic benefits of reducing exposure to indoor air pollution, especially when this was accomplished by increasing energy efficiency. [15)]

Passive design solutions can dramatically lower a building's energy usage as opposed to active design, which depends on mechanical processes for heating, cooling, ventilation, and lighting. Lower energy costs and a smaller carbon impact may result from this. Even when active design tactics are employed in a project, passive design strategies remain crucial. This is because they offer building design options that are affordable, dependable, and energy efficient. In addition to enhancing indoor comfort and energy efficiency, they also add to the visual appeal and sustainability of buildings. By utilizing natural ventilation and reducing exposure to direct sunlight, passive design solutions can produce a comfortable indoor atmosphere.

A more comfortable and healthy indoor environment free of draughts, hot spots, and indoor air pollution may result from this. By encouraging natural ventilation, minimizing indoor air pollution, and offering access to natural light, passive design solutions can enhance health and wellbeing. A building's durability and the need for regular repairs or replacements can both be increased by passive design principles, which frequently rely on robust materials and straightforward systems that require little maintenance. Passive design techniques can cut the original cost of construction and continuing operating costs by lowering the reliance on mechanical systems, making sustainable buildings more accessible and affordable for a wider range of people. By using less non-renewable resources and lowering the building's impact on the environment, passive design solutions support sustainability [15]. In order to preserve indoor conditions while moderating exterior climatic conditions, architects and designers adjust a building's thermal properties [15]. To generate comfortable conditions inside buildings, passive design maximizes the use of "natural" sources of heating, cooling, and ventilation. The inside environment is controlled by outside factors like solar radiation, chilly nighttime air, and air pressure variations. Mechanical or electrical systems are not involved in passive security measures.

Considerations for passive design may include: Location. Landscape, Orientation, Massing, Shading, material choice, Thermal weight, Insulation, Internal design, the placement of holes to allow for air, visible light, and solar radiation penetration. Including these external points some of the points have important before starting the design of any building these nine points are enhanced the passive daylight, ventilation and space conditioning, these are given as follows**:** Emphasize Cross Ventilation, Keep Spaces Open, Rethink Mechanical Design, Control Heat, Have Optimal Insulation, Use High-Performance Windows and Doors, Have Proper Solar Orientation, Design an Airtight Envelope and Build High-Performing Walls [16].

Passive House requirements can be met with the help of high-performance windows, insulation, and solar orientation. Homes with the Passive House certification consume an estimated 80% less energy to heat and cool than typical structures.

The advance daylighting system for buildings is used to enhance the daylights in the building alongwith the tradition windows and ventilators are light pipe and solar bricks. The trombe wall and rooftop solar chimney can be used to enhance the natural ventilation. The undisturbed earth temperature can be used to generate the thermal comfort in buildings by the help of earth air tunnel and borehole heat exchangers. To enhance the performance of these retrofitting for increasing the daylight, ventilation and thermal comfort some integrated approaches can be used.

2.1 Solar daylighting System

To supply or direct sunshine to a building's dimly lit areas, light pipes are used. The lined materials with high reflectivity are employed in daylighting pipes. More than 95% reflectivity anodized aluminum and coated plastic film (silverlux) [17]. The daylighting pipes have a clear top dome and are located in the roof. The top dome blocks the damaging UV rays and guards against the entry of rainfall and dust. Figure 1 displays a schematic diagram of a building's light pipe. Analysis of the light pipe's operation on bright and gloomy days revealed a percentage drop in the amount of sunshine that made it into the structure. In multi-story buildings or shopping centers, the subterranean parking is a typical element. When considering the energy efficiency of light pipes in underground parking, Shin et al. [18] calculated a 27% energy savings. In Korea, the light pipes are frequently employed. The impact of heat gain by day light pipe for deep interior spaces of structures was predicted by Hien and Chiarattananon [19]. When analyzing the light pipes, Muneer and Zhang's [20] predictive model typically takes into account both configuration and weather.

Light pipes are one of the most promising options to provide daylight into the deep spaces of not only buildings, but also for lighting the road and railway tunnels. Light pipes integrated with electric lighting along with daylight control could save 20-25% of lighting energy in building and one hundred light pipes replacing the fluorescent lamps could save 8 MWh of energy annually. Light pipe systems have found wide spread use in developed countries but in developing countries like India, which has one of the fastest growing realty sectors in the world, use of light pipes still needs to be encouraged. In India, only one company manufactures light pipe, hence there is a need to study light pipe systems and develop performance prediction models, so as to appreciate its utility and bring light pipes as a sustainable solar product into widespread use in India. Light pipes or sun tube lights are a simple way of transferring natural daylight deep into a building. Natural daylight enters the building through a clear transparent dome and is reflected down a mirrored pipe to illuminate the internal space. Light pipe lights are highly effective at transferring daylight into parts of buildings that have little or no natural lighting. They can be used to replace artificial lighting and will therefore substantially reduce the annual energy consumption of a home. In many cases, sun tube lights will be used to provide all the light for an internal space but they can also be used to compliment an artificial lighting scheme.

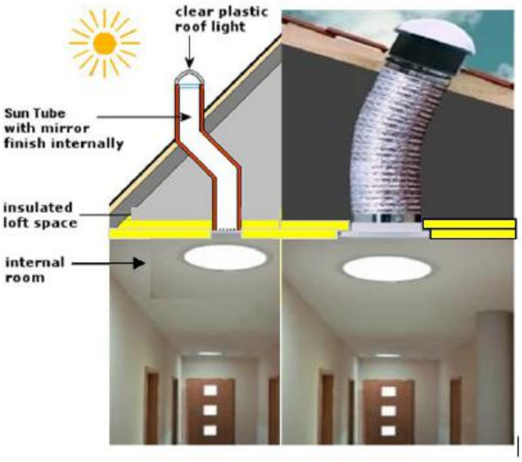

Figure 1: Light for daylighting of buildings.

Glass bricks are frequently employed in construction. It follows the most recent trends in architectural design for contemporary structures. The glass blocks can also be utilized in the roof, front and side walls, and for daylighting purposes. Figure 2 depicts the placement of glass blocks in various locations. The glass block is made up of two distinct pieces of pressed glass that have been partially vacuumed and heated to a high temperature before being cemented together. Glass blocks that transmit light up to their transmitting limits have good thermal conductivity, are soundproof, moisture-proof, and fireproof. It is enduring and makes cleaning simple. It is offered in a wide range of sizes, shapes, and prices [21].

Figure 2. Glass blocks used in buildings [21].

2.2 Passive Space Ventilation

The ventilation rate is known as air change per hour (ACH) in various building is required according to their uses like residential, multistory, office, cinema hall, auditorium, kitchen toilet, bedroom and living room etc. The requirement of some important uses in residential building is shown in table 1. The required doesn't meet naturally without in these utilities without any retro fittings like mechanical fans and blowers, solar passive architecture and solar chimneys.

Table 1: ACH requirement in residential buildings [22]

S. No.	Application	ACH as per NBC 2016	ACH as per SARC-CoV-2 Virus scenario
Residential Building			
1	Living Room	3-6	4-7
2	Bed Room	2-4	3-5
3	Changing Room, Bathrooms	6-10	8-12
4	Corridors	5-10	6-12
5	Entrance Halls	3-5	4-6
6	Garages	6-8	8-10
7	Kitchen	6 min	10 min
8	Basement/Cellar	3-10	4-12
9	Toilets	6-15	8-12

2.2.1 Trombe Wall

The trombe wall is the narrow pass of air flow attached on the wall of building which consists by a glass, absorbing wall painted black. Solar chimney or trombe wall is working on the principle of buoyancy, where the heat energy from the sun's rays causes the greenhouse effect, which warms the air and flow in upward direction. The cost is not particularly exorbitant. Buildings can be heated or cooled using a wide variety of methods. The solar chimney can also be utilized inside a wall or at roof level. The trombe wall is fitted on the vertical wall which mainly made of a black hollow thermal mass with opening at the bottom and top. The trombe wall is presented in Figure 3 which has a glass cover at the distance approximately 60mm from the black wall or black thermal mass [23]. A case study of solar chimney was studied by Lal et al. [24].

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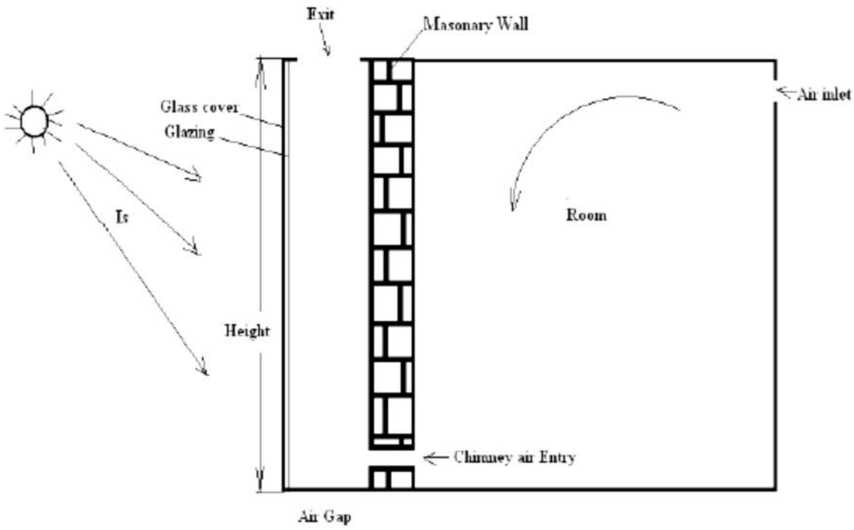


Figure 3: Trombe wall [23]

2.2.2 Roof top Solar Chimney

The thermal comfort can be improved by using SC as a solar chimney on the roof as well as a trombe wall. The solar collector located at the top of the roof is referred to as a rooftop solar chimney or rooftop solar collector (RSC). For double mode operation, such as for space heating and natural ventilation mode, Dai et al.'s [25] suggested the design of single pass and double pass RSC, as shown in figure 4 (i) & (ii). In this case, the arrangement is operated in two separate modes using the dampers 1 & 2. According to estimates, the DPRSC discovered 10% more efficiency than the SPRSC, where DP and SP stand for double pass and single pass, respectively.

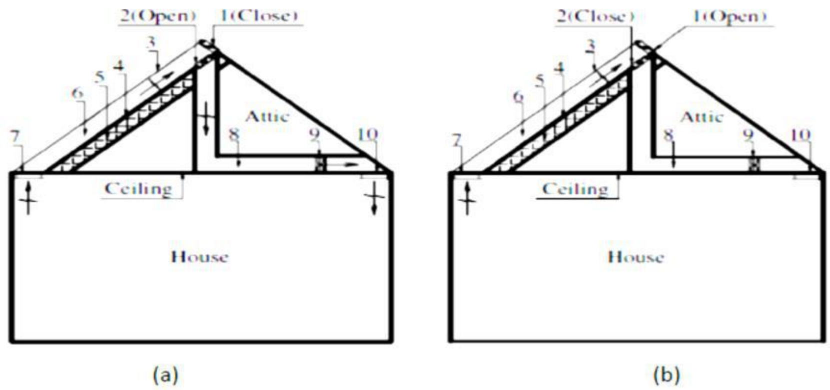


Figure 4 (i): Configuration of SPRSC (a) Room Space heating mode. (b) Natural ventilation enhancement mode. where 1—damper,2—damper, 3—glass cover, 4—absorber plate, 5—insulation plate, 6—-air channel, 7—tuyere, 8—air duct, 9—fan, 10—tuyere.[25]

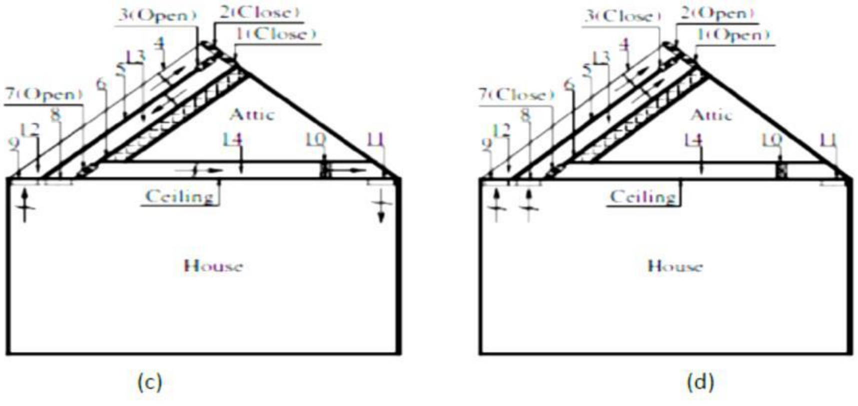


Figure 4 (ii): Configuration of DPRSC (c) Room space heating mode. (d) Natural ventilation enhancement mode, where 1—damper, 2—damper, 3—damper, 4—glass cover, 5—absorber plate, 6—insulation plate, 7—damper, 8—tuyere, 9—tuyere, 10—fan, 11-tuyere, 12—air channel 1, 13—air channel 2, 14—air duct.[25].

As the length of the RSC is increased, the air flow rate per unit area of the roof solar collector decreases. For maximum air flow, the ideal solar collector length should be shorter, between 100 and 200 cm. For maximal air flow rate, Hirunlabh et al. [26] recommended the specific arrangement that is depicted below in Figure 5. Figure 5 (b, c, and d) depicts multiple solar collectors at fixed and variable angles. It is said that the three solar collectors at varying angles—30, 45, and 60 degrees—perform better than the fixed angle at 30 degrees.

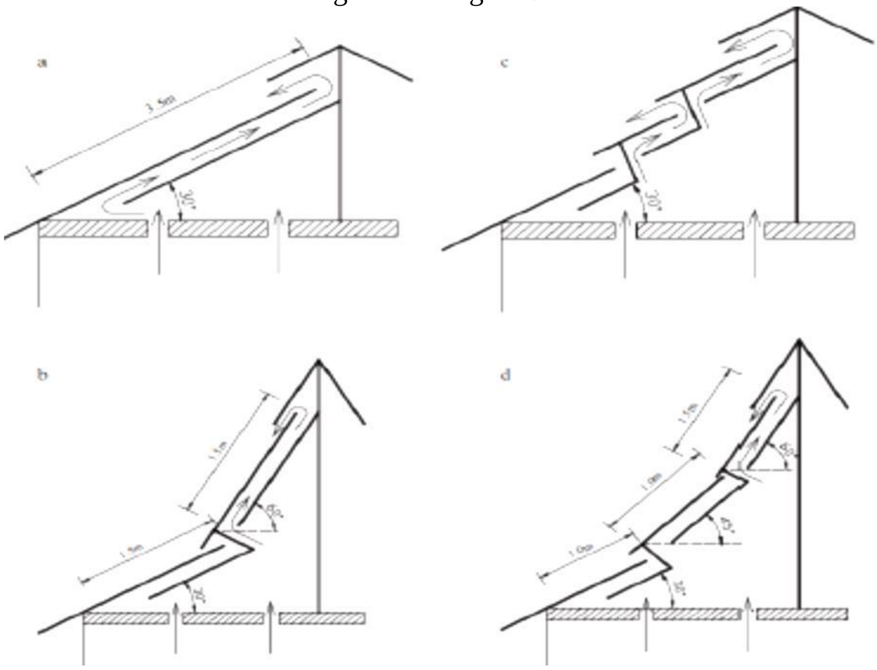


Figure 5: Four different configurations of the solar roof collectors [26]

2.2.3 Integrated Trombe Wall and Rooftop Solar Chimney

If the Trombe wall generated natural ventilation is not sufficient than the integrated approach of rooftop solar chimney can be employed? This integration is most effective at the time of COVID virus type scenario. The ventilation mode for summer is shown in figure 6. The approximate ventilation will be increased by 1.5 times the normal required ventilation. The solar chimney integrated RSC also creates some cooling effect in summer and if exit air turns to the room its can used for heating in winter.

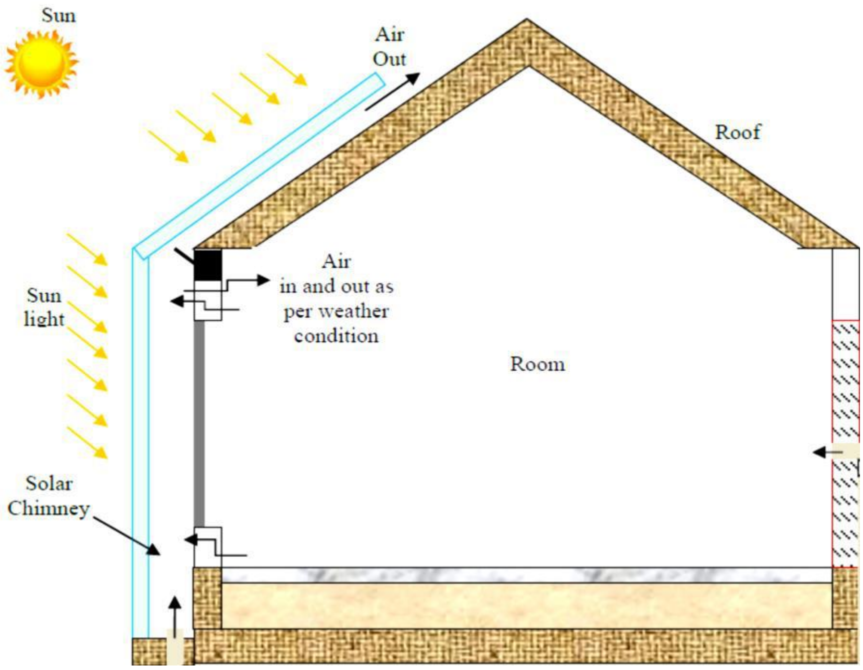


Figure 6: Trombe wall and RSC integration

2.2.4 Integration of Trombe Wall, Rooftop Solar Chimney and Evaporative cooler

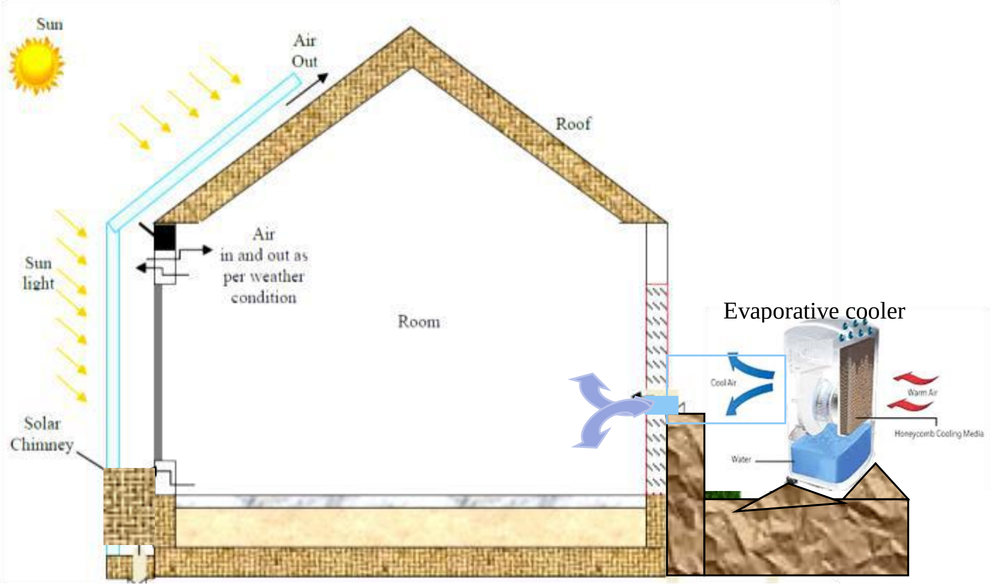


Figure 7: Integration of Trombe Wall, Rooftop Solar Chimney and Evaporative cooler

The ventilation can be increased by using the integration of TW and RSC and outside ambient air will enter in the room which found very hot in summer. It can be cooled by evaporative cooling when it passed over a water pond or for more effectiveness an evaporative cooler can be employed. as shown in figure 7.

2.2.5 Wind Towers integrated solar chimney

Table 1: Optimum Inclination of solar chimney at different latitudes [27]

S.No.	Latitude In degree	Optimum inclination of solar chimney in degree	S.No.	Latitude In degree	Optimum inclination of solar chimney in degree
1.	0	55	8.	35	50
2.	5	50	9.	40	50
3.	10	50	10.	45	55
4.	15	50	11.	50	55
5.	20	45	12.	55	60
6.	25	45	13.	60	60
7.	30	45	14.	65	60

For multistory buildings, Bansal et al. [27] suggested to employ a wind tower or wind catcher to provide the room's intake air and the solar chimney at other faces for each floor to create the stack effect stated in the solar chimney's basic design. As illustrated in Figure 8, this solar chimney has a 30 degree inclination angle, 3.0 m^2 collector areas, and a wind tower that is higher than the structure employed.

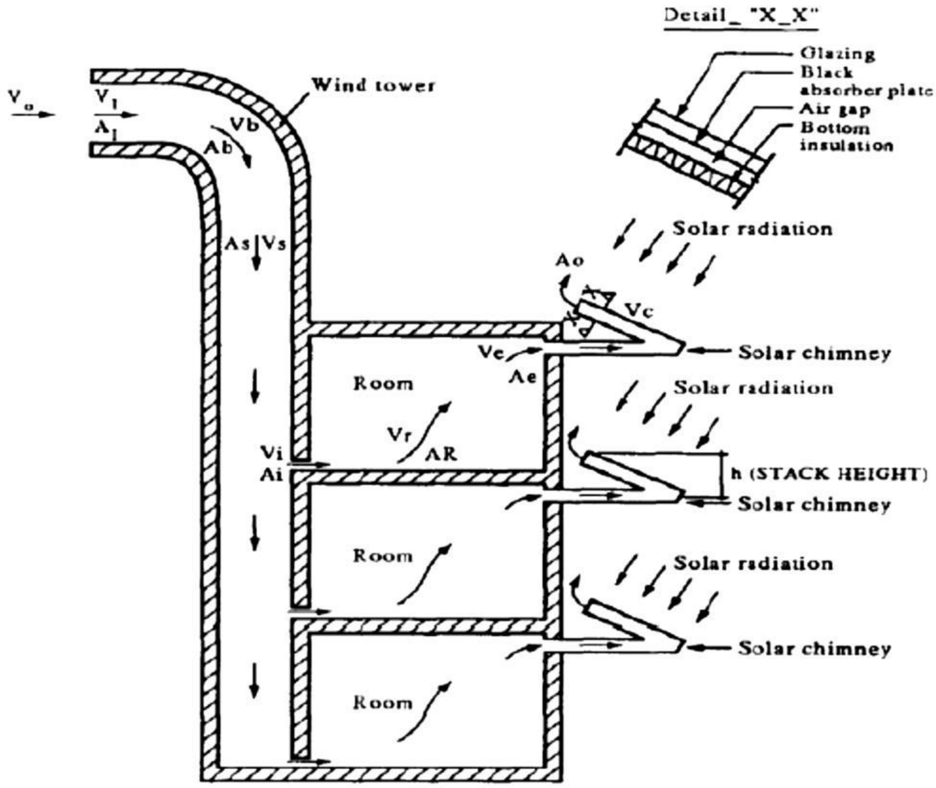


Figure 8: Schematic of wind tower solar chimney system [27]

The performance of the solar chimney is affected by its position, especially its latitude, which determined the ideal angle for the greatest flow condition. As indicated in Table 1, Mathur and Mathur [28] optimized the inclination angles for latitude between 0 and 65ºN and gave the 45 degree optimal angle for 27 degree North latitude. For Trichurapalli, India (longitude +78 69'E and latitude +10 81'S), Reddy [29] experimentally optimized the tilt angle and discovered the 45º ideal inclination angle.

2.3 Passive space heating and Cooling System (Space conditioning)

A decrease in the use of conventional energy in structures, which in turn reduces the demand for conventional energy, environmental pollution, and global warming, may be facilitated by the creative use of renewable energy for passive space conditioning in buildings. A decrease in the use of conventional energy in structures, which in turn reduces the demand for conventional energy, environmental pollution, and global warming, may be facilitated by the creative use of renewable energy for passive space conditioning in buildings. Kaushik et al [30] critically reviewed the earth air tunnel and suggested the utilization it for building space heating and cooling.

2.3.1 Earth air tunnel heat exchanger

An earth air tunnel heat exchanger (EATHE) is another straightforward technique of passive cooling and heating of a structure in which a conduit is installed underground to extract the thermal effect in air for space conditioning. The effectiveness of such an EATHE is dependent on a number of factors, including surface conditions, buried depth, tunnel length, cross sectional area, and air qualities including velocity, inlet temperature, and relative humidity [30]. The earth undisturbed temperature is utilized to transfer the heat from soil to air or vice-versa according to the seasons as shown in figure 9. In addition to adding a foundation for sustainable development, the earth air tunnel heat exchanger (EATHE) is a promising option to reduce energy demand [31-35].

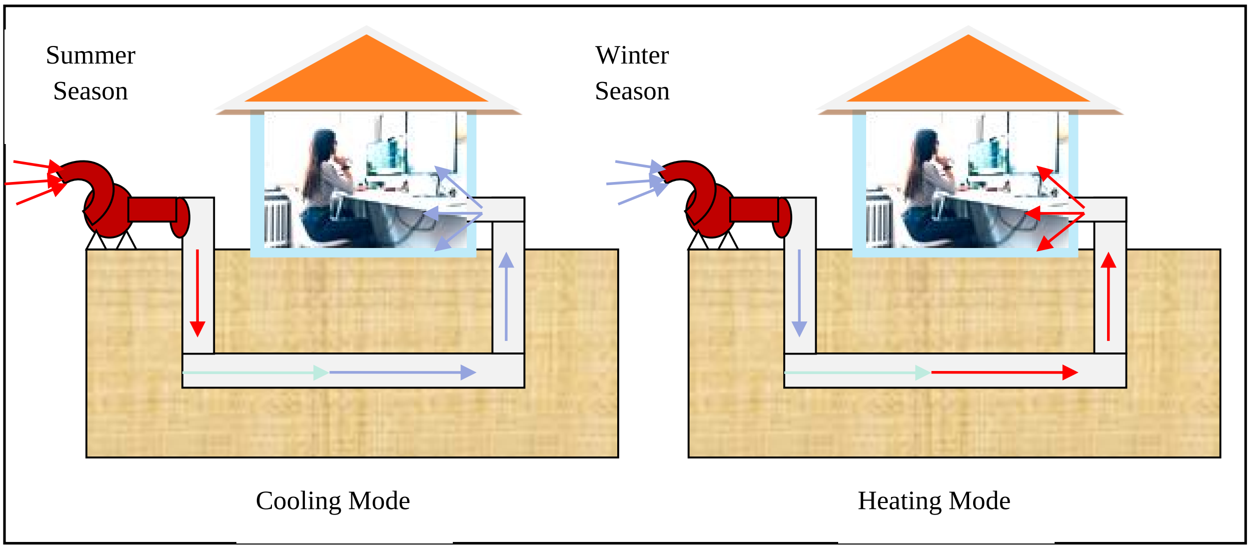


Figure 9: Earth air tunnel heat exchanger for cooling and heating mode in Buildings

2.3.2 Borehole heat exchanger

Zeng et al. [36] developed a quasi three dimensional model for heat transfer analysis of vertical ground heat exchangers. It has been possible to collect the fluid temperature profiles along the borehole depth. With a reduction in borehole resistance of 30–90%, it was discovered that twin U-tube boreholes performed better than single U-tube boreholes. The borehole's estimated dimensions are 40–200 m in depth and 75–150 mm in diameter. Lal et al. [37] experimentally analysed the borehole heat exchanger (BHE) as shown in figure 10. The pre-studies on subsurface water temperature and levels serve as the foundation for the BHE design. BHE is a good alternative for space conditioning as far as reducing CO_2 emissions and energy consumption are concerned.

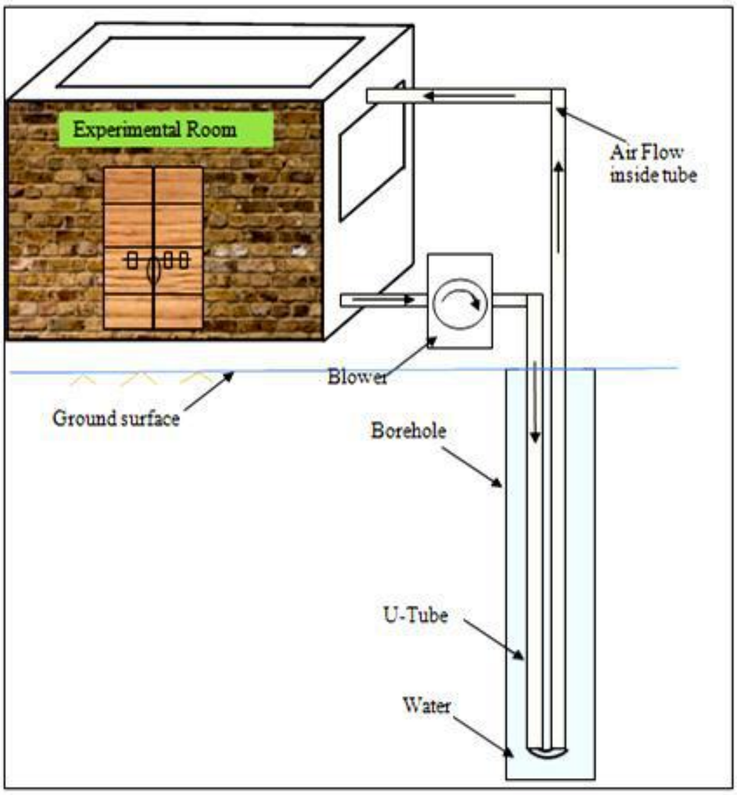
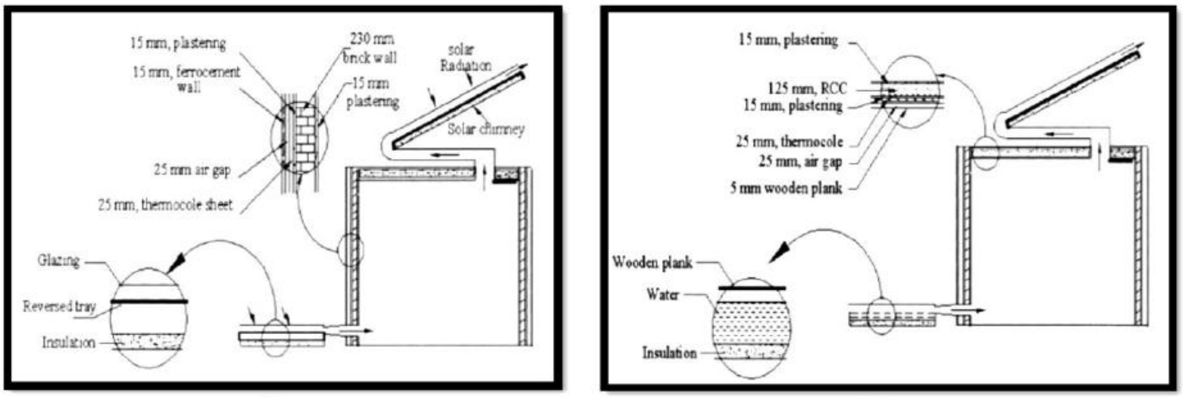


Figure 10: Borehole Heat Exchanger [36]

Lal and Kaushik [38] comparatively analysed the EATHE nd BHE and observed that the BHE is economically better than the EATHE as well as BHE takes low space than EATHE.

2.3.3 Solar chimney and evaporative cooling system

Conventional evaporative cooling is an important technique for lowering the temperature of indoor air. It is applicable to composite climatic situations. The thermal efficiency of passive solar air-conditioned buildings with evaporative cooling is discussed by Chandra et al. in their study from [39]. They tested three different evaporative cooling cases and discovered that water sprayed over the roof provides the most cooling. Figure 11 illustrates the passive heating and cooling models provided by Raman et al. [40] for the winter and summer options. Water will only be used for cooling during the summer, as seen by the cross section in the illustration. To lessen heat transfer, the roof was insulated with thermocol and hardwood blocks (falls ceiling). The ACH (Air change per hour) and flow can be increased by combining the trombe wall and RSC. Even though the cost of construction has gone up by 20%, this idea will save energy and improve thermal comfort.

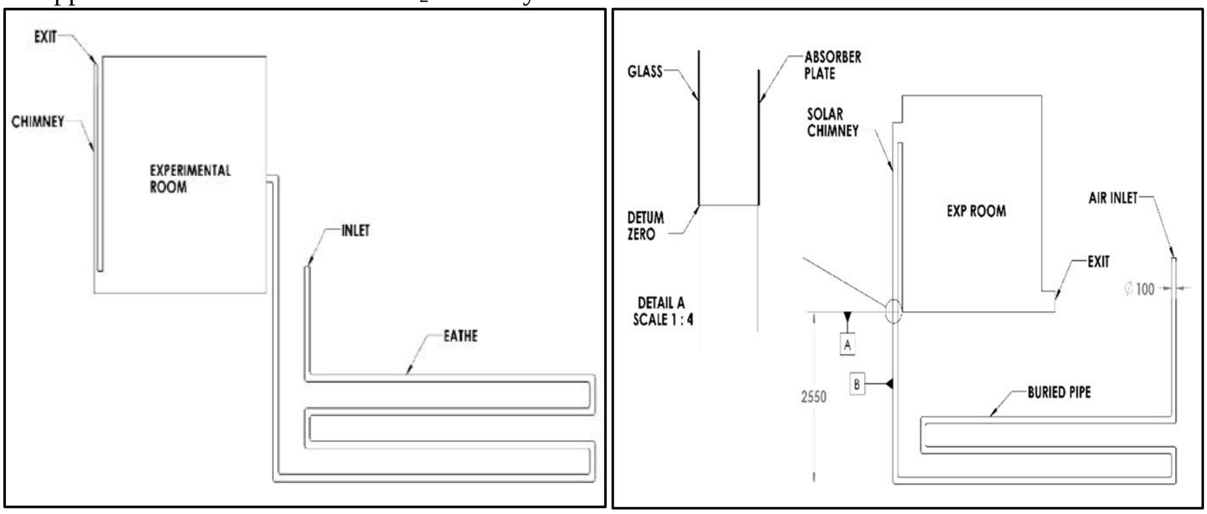


(a) (b)

Figure 11: (a) Schematic diagram of passive model 1 system for winter operation. **(b)** Schematic diagram of passive model 1 system for summer operation [40]

2.3.4 Solar Chimney and Earth air tunnel heat exchanger integration

The solar chimney integrated EATHE are commonly used when the thermal comfort (TC) is required alongwith the ventilation [41-42]. Lal et al. [42] studied the integrated approach of solar chimney and earth air tunnel heat exchanger. The two different configurations for seasonal demand of TC and ventilation is presented in figure 12 (a, b) where (a) used in summer and (b) used in winter. The thermal comfort and ventilation both have been sufficiently gained and this integration approach can save tonnes of CO_2 annually.



(a) For summer (b) For winter

Figure 12: Solar chimney and EATHE integration for summer and winter [41]

2.3.5 Solar Chimney and Borehole heat exchanger (BHE)

The solar chimney and borehole heat exchanger is effectively integrated and studied by Lal and Kaushik [43]. The CFD simulation configuration of this integrated approach is shown in figure 13. The performance of BHE is better than the EATHE and BHE is economically low cost and low pay back period. So that the integrated approach of SC+BHE has given better performance than SC+SATHE. The integration approach can be used for both summer and winter season by its exit air (from solar chimney) recirculation in the building.

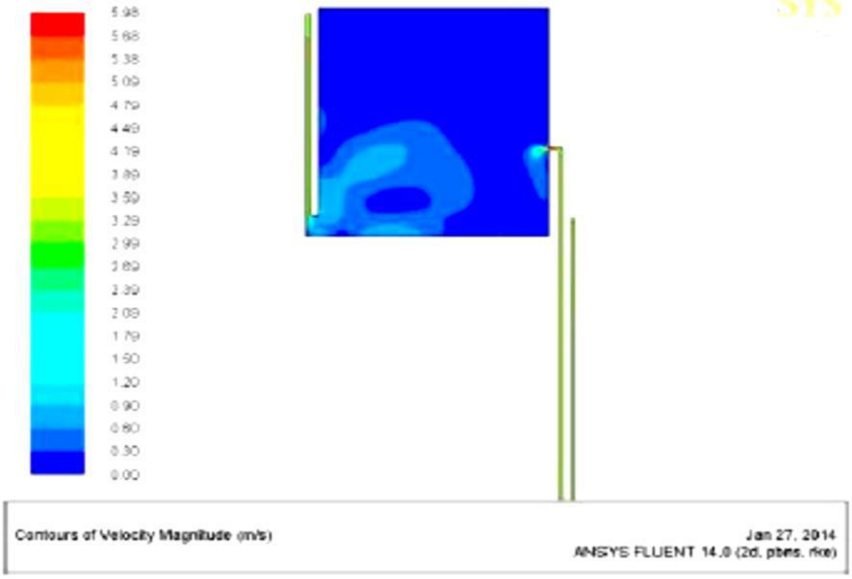


Figure 13: Borehole Heat Exchanger and Integrated with solar chimney [32].

3. Result and Discussions :

Lal et al. (2013) experimentally studied the solar chimney for a single story building and observed that the ACH 5-7 can be achieved by the application of solar chimney and it is sufficient for a nucleus family in all stages either normal or at the time of pandemic. The seasonal variation in the environment as summer and winter the environment temperature goes very high (up to 48-49°C) or very low (up to 0°C or minus). In these conditions thermal comfort in buildings are required. The commercial electricity is very costly and the environmental pollution and global warming is increasing majorly due to the large power plants. Considering these parameters, some another option other than mechanical and electrical for enhancement of ventilation and thermal comfort would be more realizable. The solar passive option can be used because it is uses from last 1000 of year by humans. The caves in forts have worked as EATHE to cool and heat the forts. This concept has to be used in the presented scenario by the researchers and applied in many buildings. The green building rating is also depends on the less utilization of commercial energy. Lal et al. [44-48] also suggested to utilize the solar chimney, EATHE, BHE and integrated approaches in building and found there is no need of commercial energy for ventilation and space conditioning in building after the application of integrated approaches, because by integrated approach it can be maintained ACH by 5-9 and thermal comfort temperature between 13-26°C for whole year in all seasons. It was also estimated the CO_2 mitigation due to the application of solar chimney, EATHE, BHE and their integrated approaches. The energy source behind the all passive options is sun energy only and it's a renewable energy. The CO_2 from the environment can be mitigated by the adopting of renewable energy option [49]. The light pipes can be used for solar daylighting in daytime for workshops, industries, underground parking and Malls etc. It is most convenient and useful method and most economic method.

4. Conclusions and future scope :

The solar day lighting through light pipes, passive heating and cooling systems of building are most feasible options for ventilation and space conditioning of buildings. The required ACH and thermal comfort can be achieved by the systems of solar light pipes, EATHE, BHE and their integrated approaches. The future scope for research of these options is given as follows:

- The solar chimney angles according to the lattitute and altitude required for ease of design
- The solar irradiance availability of the site
- Thermal mass storage in solar chimney design for night working
- Chimney Size optimization according to the LIG, MIG and HIG building size as per the government
- The material of EATHE pipe for fast heat exchanging and long life with economically viability
- The material of BHE pipe for long term utilization.
- Glass material or any other transparent materials for solar chimney and Trombe wall.
- The automation of recycling the air in the room according to the requirement of thermal comfort of building
- Rigorous study of all type of soil and EUT for ground.

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Disclosure of conflict of interest

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