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Solar air conditioning of buildings with thermosyphon systems: A review

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ABSTRACT

The major part of the energy consumed in the habitats is intended for heating (cold seasons) and air conditioning (hot seasons) to provide thermal comfort and good air quality inside the building. The addition of a solar heating or cooling system to a dwelling appears to be an attractive solution for the economy and the rational use of energy. Such system exploits and promotes the accumulation of solar heat and uses the thermal circulation of air, as is the case, for example, with the Trombe wall, solar chimneys, solar roofs, and Supply-air window which are supported by the "Solar architecture" that uses the different components of the building to take advantage of solar radiation. These systems allow us to avoid the use of energy-intensive heating or cooling devices. This work can be taken into account as a quick reference to have an overview about thermosyphon systems integrated in buildings.

KEYWORDS: Air conditioning, Trombe walls, Solar chimneys, Roof solar collectors, Supply-air window, Thermal comfort

Introduction

Thermal comfort is something that is not easy to define and insure and it is not limited to temperature, Speed and relative humidity are the main physical parameters that govern the sensation of thermal comfort, but the parameter on which to act first is the air temperature. It is necessary to limit the heat inputs through the walls and roofs of houses in warm seasons and to bring heat during cold periods. Natural ventilation and heating is the core of the bioclimatic design that not only limits the use of a mechanical ventilation system to bring in the right amount of fresh air, but also avoid the use of conventional air conditioning. Passive solar heating and cooling technologies are based on the same principle; witch is the air movement due to differences in air density induced by differences in temperature. Based on this principle, a wide variety of systems have been developed to achieve a better use of solar energy, these include Trombe walls, solar chimneys and roof solar collectors, and Supply-air windows. These systems are supported by the "solar architecture" which uses the different components of the building (roofs, walls, windows, etc.) to take advantage of solar radiation. Designers, engineers, architectures, service engineers and material providers must consider solar energy installations as a sustainable energy development [1]. The effective reduction of passive loads will depend mainly on the level of mastery of local building techniques and the materials used. Improving thermal comfort has always been the goal of a wide variety of research. For this, the objective of this paper is giving researchers a quick reference to have an overview about thermosyphon systems integrated in buildings. In the following we will present a review of the literature which groups a significant number of works carried out in this field. Section 2 is devoted to the description of the conventional Trombe wall and its new configurations, in addition to the various research works carried out in order to improve the performance of such system. Section 3 contains a description of solar chimney and certain scientific works realized in this range. Roof solar collectors will be discussed under Section 4. New systems those result from combination of previous systems are covered in Section 5. At last, the supply-air windows are discussed as passive systems.

2. 2. Solar wall

Solar walls are a technology used to passively heat a building. Solar walls are one way to achieve energy efficient building design. These walls combine exterior construction with interior devices for using solar energy to heat and ventilate indoor spaces. These walls can be installed on new buildings or can be added to old houses.

2.1. Trombe wall and its derivatives

Trombe wall is the principle used by Professor F. Trombe and architect J. Michel for the development of a prototype house in Odeillo south of France in 1967 [2]. The south facade consists of a glazing and a wall of heavy masonry whose exterior surface is painted black. The Trombe wall in its conventional configuration (Fig. 1) consists of a thick wall covered with a window, containing between them an air channel, where the massive wall absorbs and stores the solar energy through the glazing. Part of the energy is transferred into the indoor of the building (the room) through the wall by conduction. Meanwhile, the lower temperature air enters the channel from the room through the lower vent of the wall, heated up by the wall and flows upward due to buoyancy effect. The heated air then returns to the room through the upper vent of the wall [3].

Afterwards, other configurations have been developed such as the wall Trombe-Michel, whose principle of operation remains close to the wall Trombe (Fig. 2) [3, 4]. The thermal energy can be transferred from outside to the interior air layer by conduction through the massive wall. Then it can be transferred by convection while using the thermo-circulation phenomenon of air between the massive wall and the insulating wall [3]. Throw a numerical study, Jibao Shen and al [4] affirmed that the Trombe–Michel wall has better energetic performances than the classical wall in cold and/or cloudy weather.

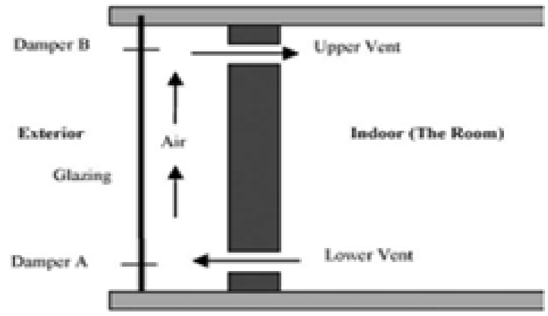


Fig.1: Schematic of classical Trombe wall [3].

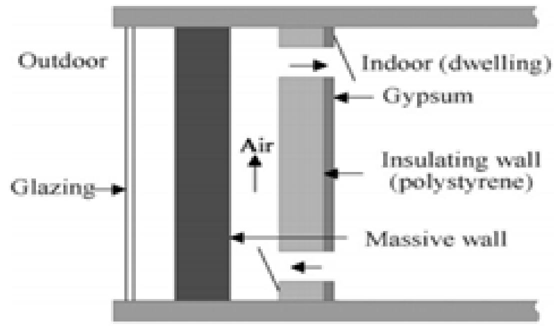


Fig.2: Schematic of composite Trombe–Michel wall [3, 4]

For enhancing the solar wall efficiency, J. Hirunlabh et al [5] have proposed a new configuration of solar wall; it consists of a glass cover, an air blade, a black metal plate and insulation (Fig. 3). The results showed that the proposed system can greatly reduce unwanted thermal gains by creating an air stream, as it can be used in the opposite way to improve heating during the winter. This proposed system was economical due to little cost of materials used.

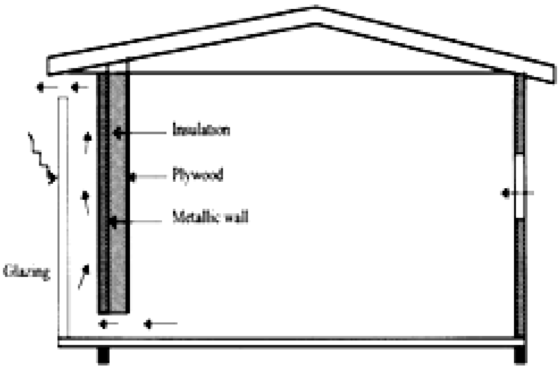
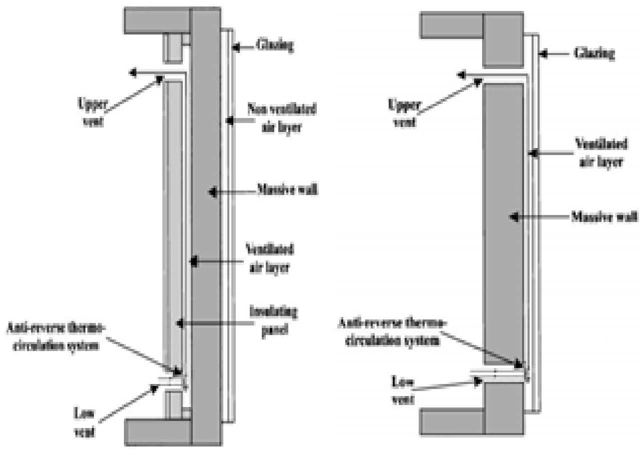


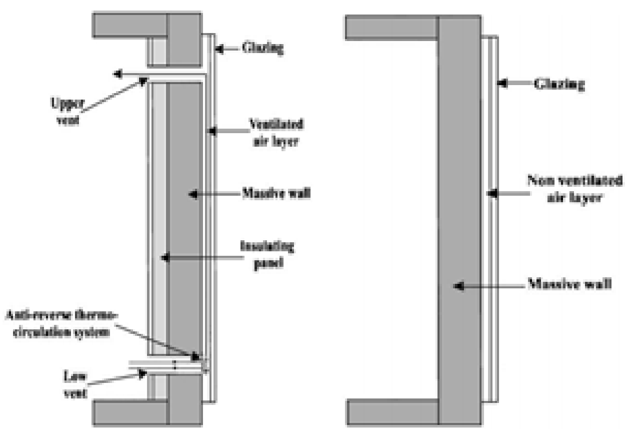
Fig.3: Schematic representation of the passive solar house and natural ventilation by MSW [5].

In order to arrive at a configuration that improves thermal comfort, L. Zalewski et al [6] have studied four types of solar wall (Trombe wall, the insulated Trombe wall, the non-ventilated solar wall and the composite solar wall) (Fig. 4). According to these authors;

the most efficient solar wall is the Trombe wall and the least efficient is the composite solar wall.



(a). Composite solar wall. (b). Trombe wall.



(c). Insulated Trombe wall. (d). Non-ventilated solar wall.

Fig.4: The four types of solar wall studied by L. Zalewski et al [6]

The passive heating technology of a ventilated Trombe wall looks interesting to be applied to the Algerian Sahara, where K. Hami et al [7] found that the temperatures obtained in the zone of habitation were in the range of those of the thermal comfort.

2.2. Solar wall with porous medium

In 1990, Z. G. DU and E. Bilgen [8] have studied a new idea of adding a porous layer (which acts as a porous absorber) to the solar wall (Fig. 5), this porous absorber offers the possibility of improving the heating and thermal resistance of the complex during the night and on cold days, it can function better than a conventional Trombe wall during the winter if the dimensions and the porosity of this layer are well chosen. The influence of orifice opening and position as well as the non uniform heat generation within the porous medium have been studied in detail with the Darcy number varying from 10-8 to 10-2, it was found that the Openings position has important effects on heat transfer for small Darcy number this influence decreases obviously due to the increased penetrability of porous layer. After that W. Chen and W. Liu have conducted a series of studies [9, 10] (See Fig. 6), they have analyzed the influence of the particle size, porosity, thermal conductivity of porous layer and the porous absorber position in the solar composite wall on the air temperature in the heated room, they affirmed that all these factors should be taken into account for a better design of the heating system and should be chosen properly to avoid the occurrence of the overheating and the no reaching the heating requirements when the solar radiation is available.

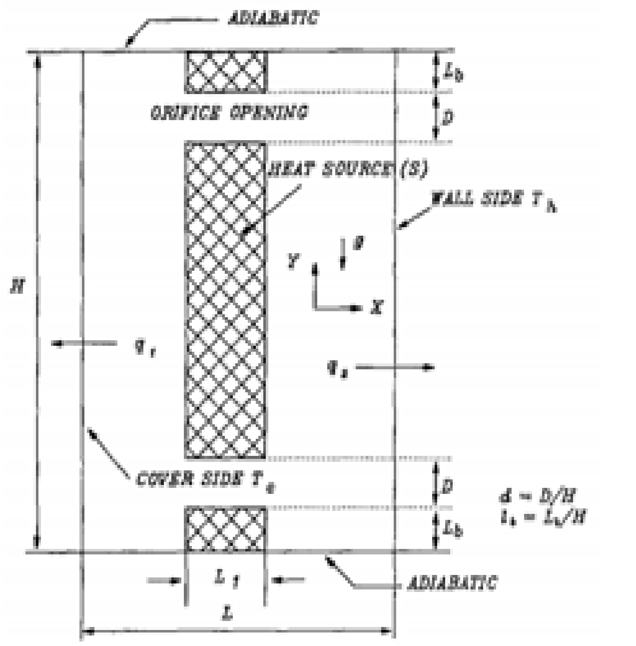
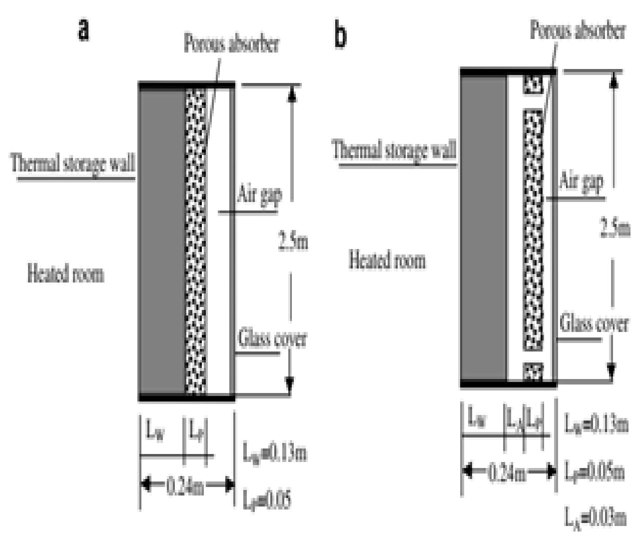


Fig.5: Modified Trombe wall solar collector with a porous layer as an absorber [8].



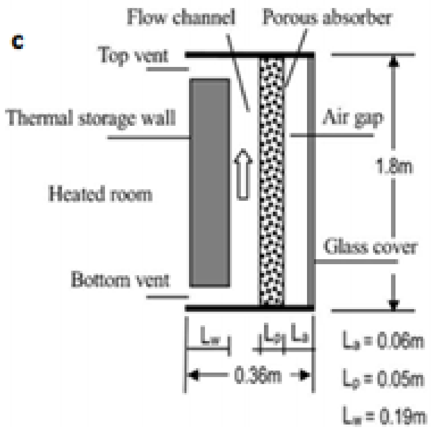


Fig.6: Schematic of a composite wall solar collector with a porous absorber: (a) contact type passive solar composite wall with porous absorber, (b) separation type passive solar composite wall with porous absorber [10] and (c) vents in thermal storage wall [9].

According to the Experimental study of H. Onbasioglu and A. N. Egrican [11] it is clear that night time cooling occurs by natural convection, driven by reverse thermo-circulation as well. Therefore, the vents should be covered to prevent the reverse thermo-circulation during the night time. Thus, the use of double glass covers improves the performance of this system, as it is recommended to insulate the inner surface of the wall to avoid overheating due to radiation and convection of the wall inward [12]. According to Guohui Gan [13] the use of double glazing instead of single glazing for a Trombe wall system not only reduces heat losses in winter but also enhances passive cooling in summer.

2.3. Solar wall with phase change materials

The incorporation of phase change materials (PCM) in the building sector has been widely investigated by several researchers. Throw an experimental study of a small-scale Trombe composite solar wall (Fig. 7) where, the phase change material was inserted into the wall in the form of a brick-shaped package, Laurent Zalewski et al [14] showed a very different thermal behavior under dynamic conditions; When this material can store more heat than the same volume of concrete (for the same temperature range). In other work, the concrete storage wall has been replaced by a cement mortar (Fig. 8) in which a phase change material (microencapsulated wax) has been integrated, Enghok Leang et al [15] have compared between the classic wall (concrete storage wall) and the wall incorporating PCM in the mortar storage wall (M_PCM), the obtained results show particularly a large capacity of heat recovered by M_PCM storage wall (+50% compared to the concrete storage wall).

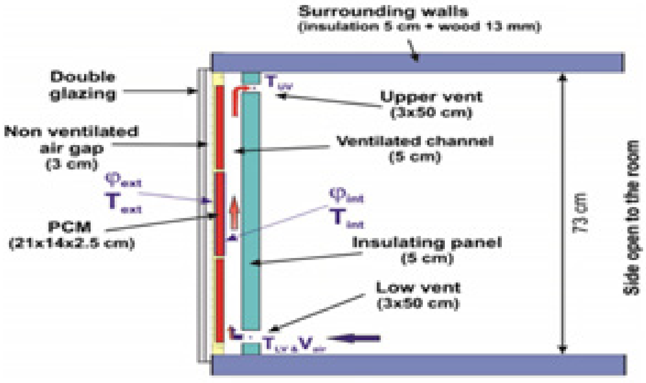


Fig.7: Storage wall incorporating rectangular bricks containing a phase change material [14].

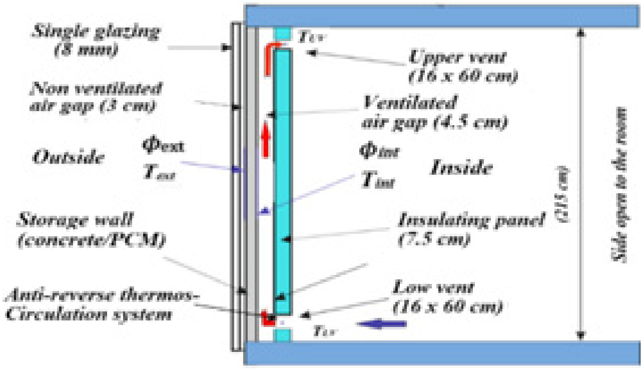


Fig.8: A composite solar wall incorporating M_PCM in its storage wall [15].

Using phase change materials (PCMs) provides an elegant and realistic solution to increase the efficiency of the existing cooling, heating, and ventilation systems [16]. It has been demonstrated that the PCM incorporation into building envelopes can provide an annual energy savings of 16-25% for the climate zones of Melbourne and Sydney respectively [17]. Several studies have demonstrated that the use of PCMs in well-insulated buildings can reduce heating and cooling energy in residential buildings by as much as 25% and obtain similar reductions in the power necessary for air conditioning [18].

2.4. The parameters affecting the operation of solar walls

Several researches have been realized to improve performance of this system, these studies showed that for a solar wall used for cooling or heating, the ventilation rate (induced by buoyancy forces) is affected by several parameters as solar gains, temperatures, length, wall thickness and the distance between the wall and the glass cover..Etc. To ensure a good thermal comfort it is necessary to take into consideration the solar energy during the architectural design [13]. Throw a numerical investigation A.M. Rodrigues et al [19] found that channel widths and hot wall fluxes affect the natural convection in solar wall. In their analytical study (validated by an experimental test) V. H. Hernández Gómez et al [20] found that the increase in the height of the wall is not advantageous, whereas an increase of the width of the air channel and of the vents is recommended. The air flow rate increased with increasing wind speed [21].

3. Solar chimneys

Solar chimneys, also called heat chimneys, can also be used in architectural settings to decrease the energy used by mechanical systems. The chimney has to be higher than the roof level, and has to be constructed on the wall facing the direction of the sun, so it can either be vertical or inclined and can be categorized into two groups: roof solar chimneys are installed on the roofs of buildings (Fig. 9) and wall solar chimneys are installed along the walls of buildings (Fig. 10) [22]. The driving force which controls the airflow rate through the solar chimney is the density difference of air at inlet and outlet of the chimney [23]. A solar chimney typically consists of an absorber wall, an air gap and a glazed wall. A solar chimney can generate air movement in the building and improves internal comfort not only by cooling (during the summer) but also by heating (in winter) if a fan is used which directs the warm air to the interior. According to Guohui Gan [24]; if solar energy is used for passive cooling, the solar chimney is best compared to a Trombe wall. The induced air stream by solar chimney can be used for ventilation and cooling in a natural way (passive), without any mechanical assistance [25]. Solar chimneys are always beneficial to reduce up to 20% overheating during hot seasons [26]. In hot climatic conditions, when windows are kept closed or covered for preventing direct entry of solar heat, concept of solar chimney can be used by making minor modifications in the existing window design [27].

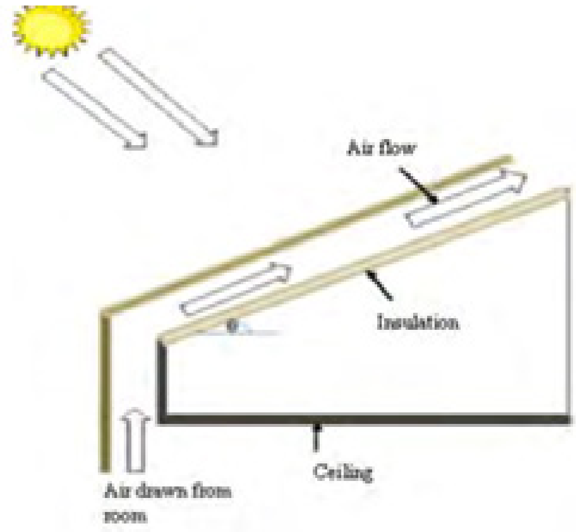


Fig. 9: Schematic of a Roof Solar Chimney [22].

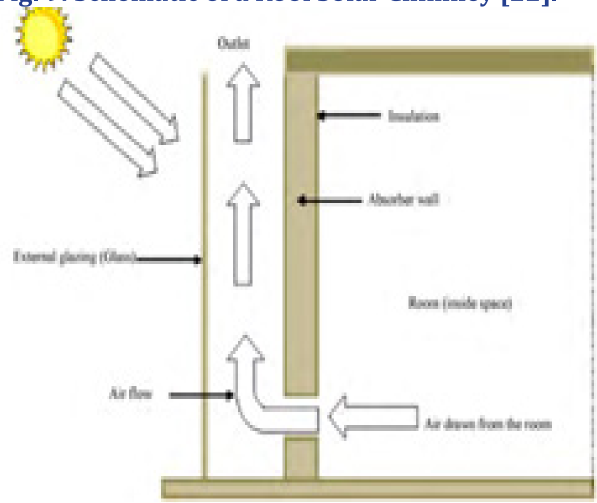


Fig. 10: Schematic of Wall Solar Chimney [22].

3.1. Solar chimney with single-cavity

P. Raman et al [28] have developed two passive solar systems (Fig. 11) for heating and air conditioning that can provide thermal comfort throughout the year in different climates, the combination of Trombe wall and RSC were used to increase the ACH (Fig. 11(a)), the cross section shows that water will be used for summer cooling only and the roof was insulated by thermocole and wooden blocks (Fig. 11(b)), in the face of the increasing of electricity costs this passive system seems to have good potential. Sumathy et al [29] Where proposed to enhance natural ventilation in a solar house by a chimney with solid adsorption cooling (Fig. 12), the solid adsorption bed mounted on roof at β angle, the heat received by glazing at top of adsorption bed perhaps bed generate a cooling effect, after that cooling is transferred to cavity from which air flowing and enter the room. The night ventilation increased up to 20%.

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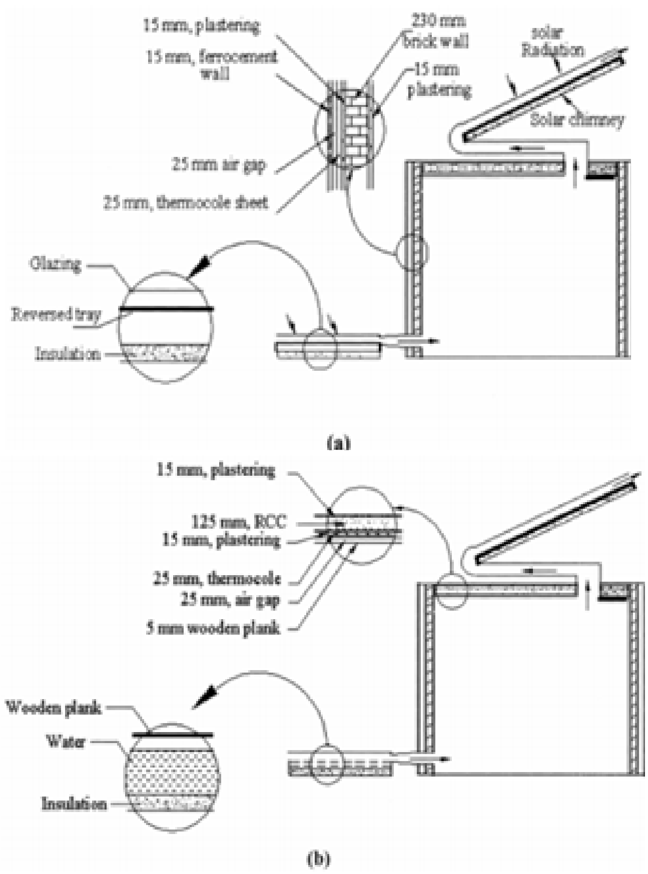


Fig.11: Schematic diagram of passive model system for winter operation (a) and summer operation (b) [28].

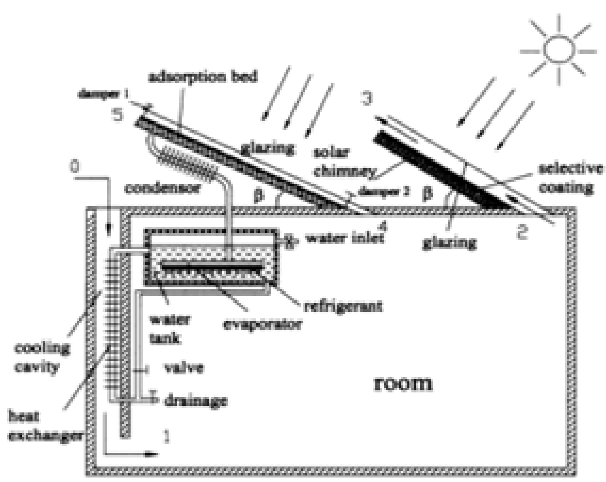


Fig. 12: Schematic of the solar house with solar chimney and adsorption cooling cavity [29].

Duan et al [30] have proposed to add mechanical ventilation system with solar chimney (Fig. 13), after their theoretical analysis of the mechanical ventilation rate impact on the behavior of combining buoyancy and mechanical force-driven flows they observed that the increasing mechanical ventilation rate induce an increase in the total ventilation rate. But due to the mechanical ventilation inflow adds pressure to the interior space that may inhibit natural inflow or could even reverse.

Throw a numerical and experimental study A. A. Imran et al [25] affirmed that the induced air stream by solar chimney can be used for ventilation and cooling in a natural way (passive), without any mechanical assistance and there is a potential of inducing ventilation corresponding to 50-425 m3/h air flow rate for 150-750 W/m2 solar radiation incident on inclined chimney.

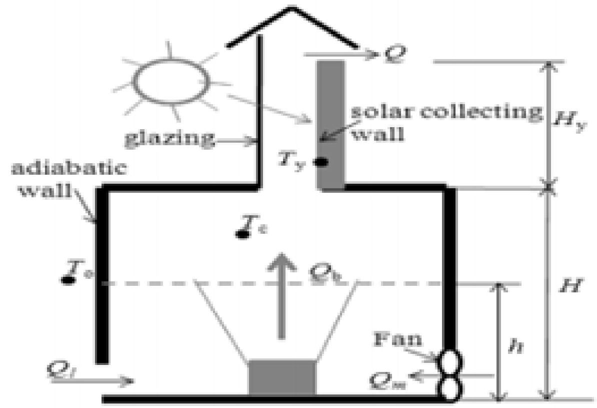


Fig.13: Schematic view of displacement ventilation enhanced by solar chimney and fan [30].

To demonstrate that the solar chimney can used to ventilate buildings with many floors, G. M. Mekkawi and R. Ali Elgendy [31] have conducted a numerical investigation, where, the studied chimney is installed on a single family two-storey housing prototype with built up area of 135 m^2 (Fig. 14), analysis is conducted to study the effect of air gap width at different values of 0.2, 0.4, 0.6, and 0.8m to test the thermal performance and comfort levels within the selected room. The results show that the installation of solar chimney (of cross section 0.4x1.5m or 0.6x1.5m with fixed height of an additional 2m above the roof) can decrease average daily operative temperature from 29.45 C° to 28.64 C° and increase the air velocity by 50%

For enhancing thermal comfort in Egypt; Ahmed Abdeen et al [32] have realized a work in which they studied experimentally and numerically a solar chimney (Fig. 15) in order to maximize indoor air velocity induced by natural convection. The authors have integrated a variety of chimney parameters, including the height, width, inclination angle, and air gap between the glass and the absorbing wall under different solar intensities. The optimal solar chimney derived from this study, which features a 1.85 m height, 2.65 m width, 75° inclination angle, and 0.28 m air gap, successfully enhances thermal comfort under solar intensities higher than 500 W/m2.

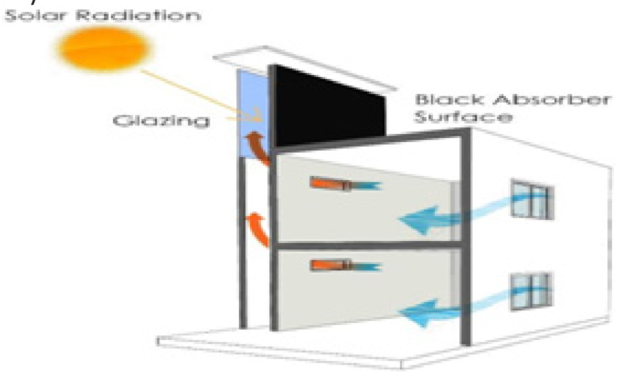


Fig. 14: Operation of Solar Chimney illustration [31].

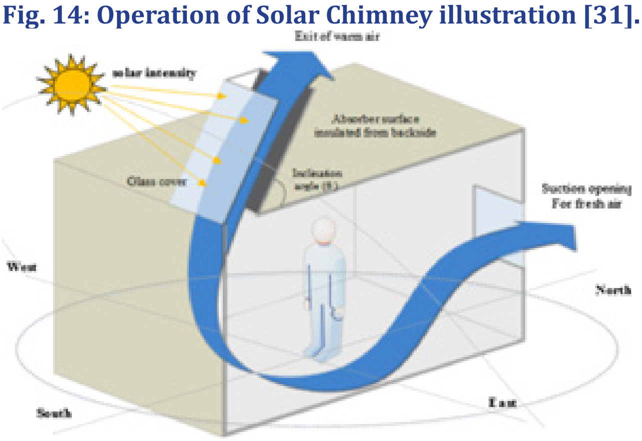
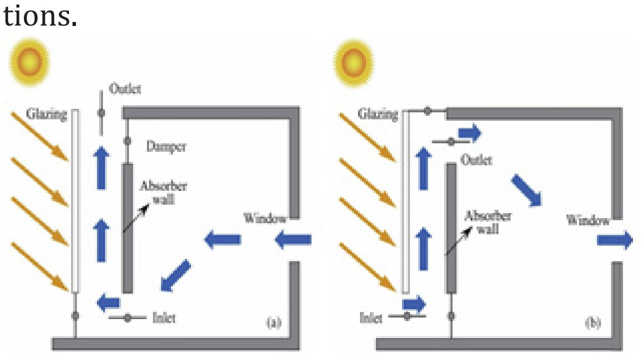


Fig. 15: Diagram of a single room with a solar chimney [32].

For the reason that the room configuration shows considerable influences on solar chimney performance, Long Shi [33] have investigated theoretically four types of solar chimney under both cooling and heating modes (Fig. 16: (a) et (b)). At the last they developed theoretical models to predict the volumetric flow rate through the chimney cavity. Their results show that to heat a typical room, fresh-air heating through the cavity (Fig. 15: (c)) shows the highest airflow rate but with the lowest temperature, which can be applied to regularly occupied building under cool weather conditions, Fresh-air heating through the room shows an opposite way, which is suitable for regularly occupied buildings under cold weather conditions.



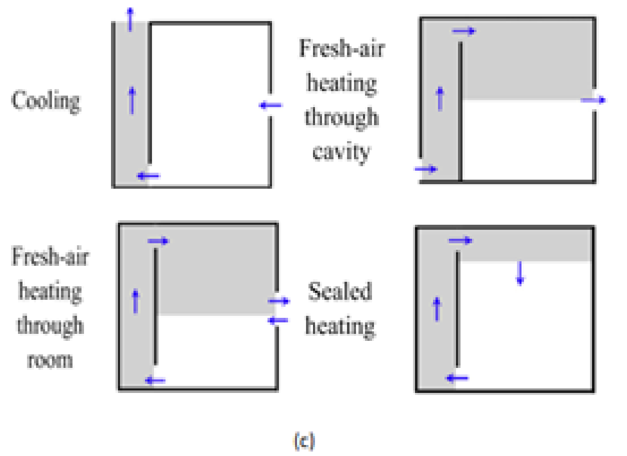


Fig. 16: Typical wall solar chimney under: (a) cooling mode; and (b) heating mode; the four studied SC types [33].

3.2. Solar chimney with dual –cavity

A double cavity solar chimney can generate maximum volumetric flows of 240–700 m^3/h and 180– 580 m^3/h to both seasons [34]. For example, I. Zavala-Guillén et al [35] suggested a SC a double air channel solar chimney (SC-DC) (Fig. 17). The heat transfer analysis of this system, aiming to determine the configuration that maximizes the mass flow rate, showed that the optimum length L of the SC-DC is similar to the value reported for a conventional chimney, whereas the optimum air spacing b is smaller than the one of a conventional SC, and the optimal configuration can reaches a thermal efficiency of 38.5 % and a mass flow rate of up to 0.1072kg/s. To improve ventilation efficiency, H. Jones et al [36] have tested experimentally thermal flows in a dual-cavity solar chimney where the surface that absorbs and reradiates the incident solar radiation is made of black aluminum foil held taut between two frame struts, the cavities can be blocked at the base of the chimney cavity both vertically and horizontally (to allow for a variety of cavity arrangements, tests were performed on several arrangements) of tinted film on the glass panel, and opening or blocking the rear cavity to test the dual and single cavity layouts (Fig. 18), the results of the study indicate that the dual-cavity system appears to improve the air flow rate through a solar chimney and the similarity of the overall envelope of temperatures for configurations C, D and E is promising.

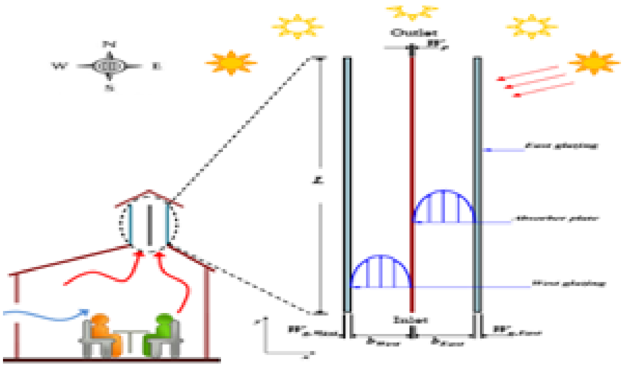


Fig.17: Transverse section of the SC-DC with an orientation East-West [35].

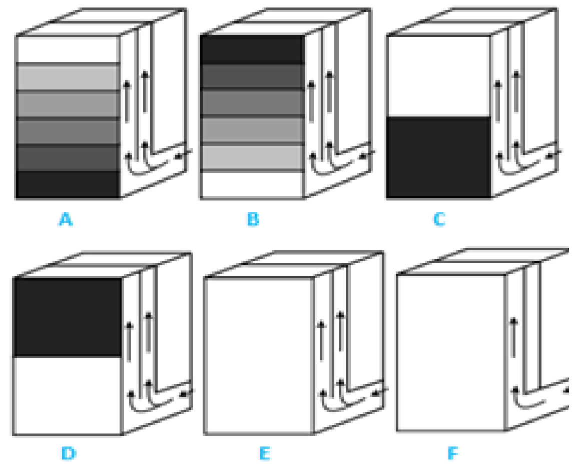


Fig. 18: Arrangements of cavities and tinting used in experimentation; (A, B) Six-level tinting, (C, D) Two-level tinting, (E) untainted glass configuration in combination with the dual-cavity arrangement, (F) untainted glass configuration in combination with a single-cavity arrangement [36].

Through their numerical investigation of a solar chimney used for natural ventilation tested by selecting different positions of absorber namely: at the back side, front side, and at the middle of the air gap (Fig. 19), Karima E. A and Khawla N. H [37] showed that a solar chimney with absorber at the middle of the air gap (as a double air channel solar chimney) gives better ventilation performance.

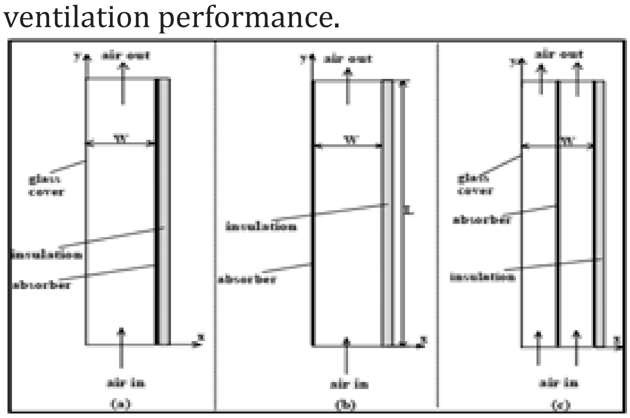


Fig. 19: Schematic Diagram of the Cases Studied of Solar Chimney. a) absorber at back side, b) absorber at front side, c) absorber at the middle of air gap [37].

3.3. Solar chimney with phase change materials

The phase change material (PCM) offers a number of advantages like its high storage capacity and isothermal characteristic during the transition of phase what leads to large space savings and provide much better thermal comfort in space heating applications. For this raison it has recently received a great deal of interest. In the aim of solar chimney development, Yongcai Li [38] has set up a full scale solar chimney rig with optimum geometries (Fig. 20) for investigation of its thermal performance when the pre-selected PCM was applied to it, the PCMs used in this research are paraffin RT 25 and paraffin RT 42 where three different heat fluxes of 700, 600, and 500 W/m2 are studied. Though this experimental and numerical results it was indicated that the PCM-based solar chimney can provide a relatively constant mass flow rate and outlet air temperature during phase change transition, but the thermal performance characteristics of the PCM based solar chimney should be studied further, due to the complicated heat transfer characteristics of the PCM.

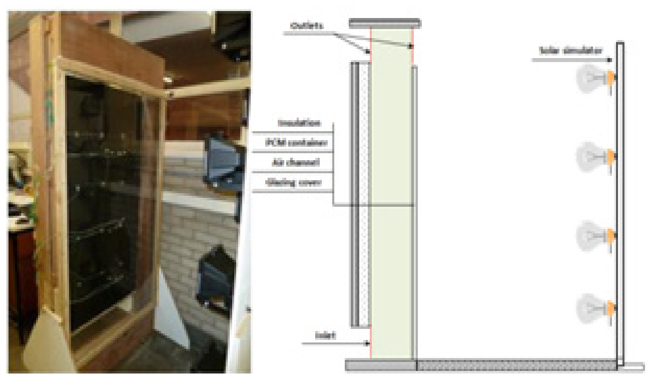


Fig. 20: Photo and schematic of solar chimney with pre-selected PCM [38].

A solar chimney is an unstable system because it is not able to work for natural ventilation during the nighttime and fluctuation of solar radiation during the daytime changes air flow rate. According to Y. Kaneko et al [39], the idea to solve these problems is the usage of the latent heat where the latent heat stored in daytime is available for the nighttime ventilation by a solar chimney, so they have developed a solar chimney with PCM (Phase Change Material) storage, which was encapsulated and packed behind the black coated absorbing aluminum (Al) plate as showed in figure 21. They observed that the integration of PCM storage inside the solar chimney is useful for natural ventilation in the evening and night, if PCM completely melt in the daytime and it supply the airflow rate of 100- 400 m3/h.

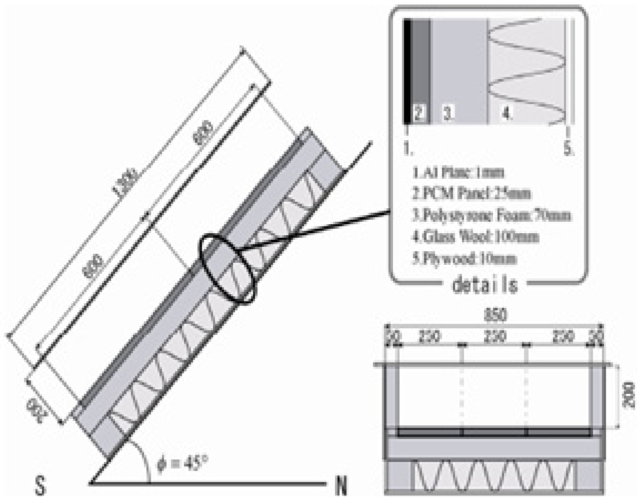


Fig. 21: Cross-sectional view of chimney with built-in PCM

The major disadvantage of such system is that most of the stored energy is lost through glass cover to ambient by radiant heat transfer. Therefore, reducing the radiation heat transfer coefficient of glass cover can increase the night ventilation effectively [40].

3.4. Parameters affecting the operation of solar chimney

The thickness of a solar chimney has a significant impact on its effectiveness [21, 41, 42, and 44] where it was found that the ventilation rate increases with increasing thickness [24, 25]. With a numerical simulation of buoyant air flow in solar chimneys and double facades for natural ventilation of buildings, Guohui Gan [25], show that the optimum width was found to be between 0.55 and 0.6 m for a solar chimney of 6 m high but the increase in ventilation was small when the width was larger than 0.7 m. For 2.2 m of solar chimney, the optimum solar chimney width was about 0.2m for which the mass flow rate is in order of 0.18 m3/s [44]. Under Spain's weather a solar chimney made from concrete with 0.24m thickness and 0.145m depth can reaches its higher temperature 2 h and generates a mass flow rate of around 0.010kg/s [45]. Surface radiation changes the flow, temperature field and Nusselt number in the positive direction, and improves the performance of solar chimneys [30, 46]. According to an experimental study of a solar chimney, Xu Jianliu and Liu Weihua [47] have found that an inclination angle of 45° gives maximum ventilation and that the latter increases with the increase in the aspect ratio between the length and the thickness of the chimney. Lee et al [48] have found that optimal configurations of the solar chimney were: high transmissivity glass, rectangular-tubes absorber plate, tilt angle of 45º, black polished surface, and airflow length of 4 m. But Imran et al [25] have mentioned that the optimum chimney inclination angle was 60° to obtain the maximum rate of ventilation, at this inclination angle, the rate of ventilation was about 20% higher than 45°. According to the numerical study of R. Bassiouny and N. S.A. Korah [49] an optimum air flow rate value was achieved when the chimney inclination is between 45° and 70° for latitude of 28.4°. Jyotirmay Mathur et al [50] have indicated that the optimum chimney inclination varies from 40° to 60° depending on the latitude of place. As example at Jaipur (India) 45° is found to be optimum for obtaining maximum rate of ventilation. The increase in the height of the solar chimney can lead to an increase natural ventilation rate for a relatively smaller time scale ratio, but reducing gravity increased significantly for a larger time scale ratio [31]. Experimental investigations on a small size solar chimney of Jyotirmay Mathur et al [27] show that the rate of ventilation increases with increase of the ratio between height of absorber and gap between glass and absorber, where, highest rate of ventilation induced with the help of solar energy was found to be 5.6 air change per hour in a room of 27 m3, at solar radiation 700 W/m2 on vertical surface with the stack height-air gap ratio of 2.83 for a 1 m high chimney.

The environmental parameters, namely, the solar radiation, wind and ambient air temperature highly influenced the performance of the solar induced ventilation [51]. The results of Gan and Riffat [52] and Harris and Helwig [53], based on CFD modeling techniques, revealed that double glazing gives a slightly better performance than single glazing. For low intensities of solar radiation, the effect of glazing was much more significant than for high intensities of solar radiation [52, 22].

The layout of solar chimney in different parts of the building affects the ventilation rate and performance of solar chimney due to its effect on air flow rate, Somaye Asadi et al [54] have found that every solar chimney position provides necessary ventilation rate for spaces attached to it but its locating in east-southern part of the building provides maximum ventilation rate due to the maximum radiation and two side absorbing wall.

4. Roof solar collectors

When the home had no openings, the temperature inside is considerably higher than the ambient, especially during the afternoon hours. Therefore induced ventilation is recommended to balance the internal temperature to that ambient [55]. The integration of the cavities of ventilated air in the roofs is effective for the discharge of the solar gains [56]. The ventilation by solar roofs can work better than a Trombe wall in hot climates because these offer a large surface for collecting solar energy and consequently of air with higher temperatures [3].

4.1. Improvement of the roof solar collector efficiency

Several research studies have been carried out with the aim of improving the efficiency of such systems. J. Waewsak et al [57] have presented an experimental investigation of a new concept of bioclimatic roof (Fig. 22) composed of a combination of CPAC Monier concrete and transparent acrylic tiles on the outer side, air gap and another combination of gypsum with an aluminum foil board and translucent sheets on the room side, the idea of this system is to create a ventilation rate meaning to improve thermal comfort. The authors assumed that it is very interesting and they demonstrated that this innovative bio-climatic roof could reduce heat gain significantly, provide sufficient lighting for housing without any overheating and induce significant air change.

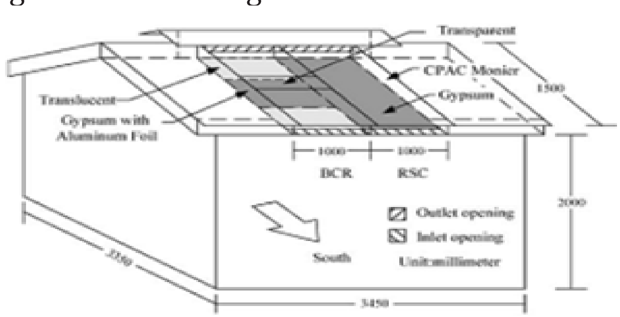


Fig.22: The concept developed studied by J. Waewsak et al [57].

A double air passages roof solar collector can operate with high efficiency in heating and ventilation spaces, for this, X.Q. Zhai, et al [58] have developed a model of a single room for witch two types of solar collectors with single and double air passages are integrated on the roof (Fig. 23 and 24). The comparison between these two collectors showed that the second type can improve the thermal gains by 10%.

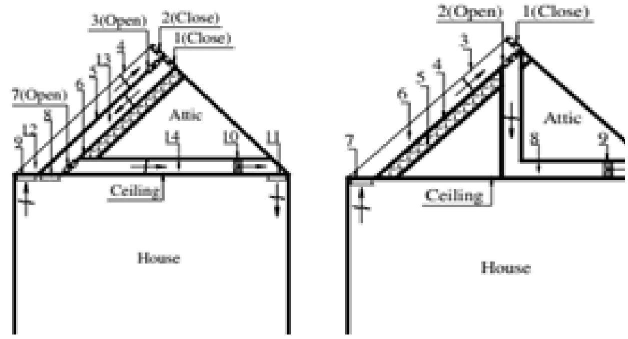


Fig. 23: Heating System: a) Double air passage, (b) Single air passage [58].

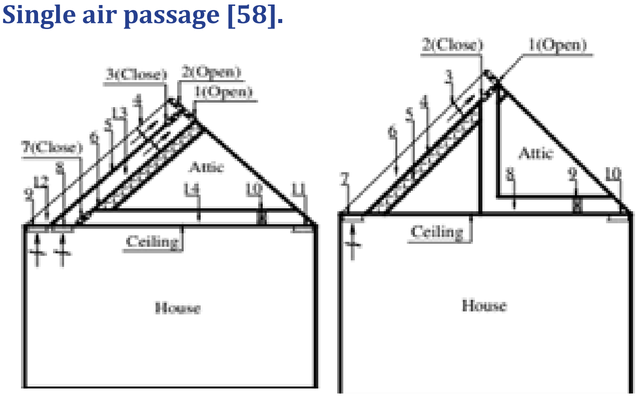


Fig. 24: Ventilation mode: a) Double air passage, (b) Single air passage [58].

To release the solar gains to the outside, a new concept of integrated solar panel roof which contains a radiative barrier (Fig. 25) was proposed by Pei Chi Chang et al [59]. The authors affirmed that a double roof structure, formed by a roof plate and an aluminum foil-PP (polypropylene) board-RC slab, can achieve good performance of heat barrier and is highly recommended.

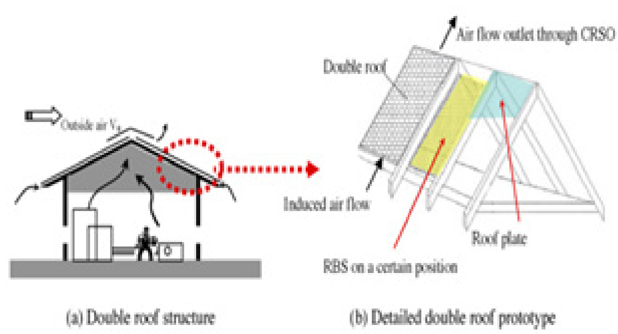


Fig. 25: Experimental prototype developed by PeiChi Chang et al [59].

P.H. Biwole et al [60] have proposed to add a per-metal vapor to an existing roof (Fig. 26), to improve the passive cooling of buildings and reduce the cost of air conditioning in summer in dry tropical countries, they showed that the optimum efficiency can be easily reached with a double-skin structure with a 0.15 emissivity of sheet iron, and 5 cm-thick insulation

Fig. 26: Experimental setup and numerical model of roof invested by PH Biwole [60].

To enhance the performance of roof solar collector (RSC) for reducing heat gain and increasing the ventilation rate inside houses, J. Khedari et al [61] have proposed to install a simple PV ventilation system in the gap of RSC. The RSC is composed of CPAC Monier concrete tiles at the outer side, air gap and gypsum board at the house side (fig. 27). In this work the air renewal powered by the PV, corresponding to a RSC unit was approximately 100-250 m3/h, these levels are 2 to 4 times higher than those obtained with natural ventilation induced by RSC, so PV-powered RSC is an interesting option in the sense that it promotes solar energy and conserve energy.

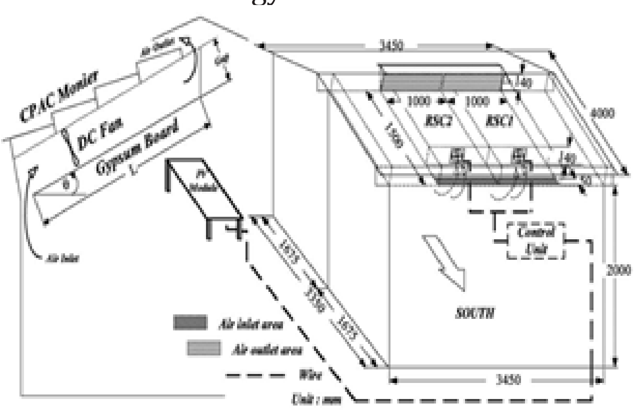


Fig. 27: Schematic representation of the PV-powered RSC [61].

Chi-ming Lai et al [62] have carried out an experimental study (Fig. 28) in which they were exposed an open-ended parallel plates to lighting radiation to simulate a double-roofs subjected to solar heat, they have tested the effect of low-cost radiant barrier on the system, they found that it can be very effective to prevent the roof heat from incoming into the building by placing a low-cost radiant barrier on the top of lower plate structure.

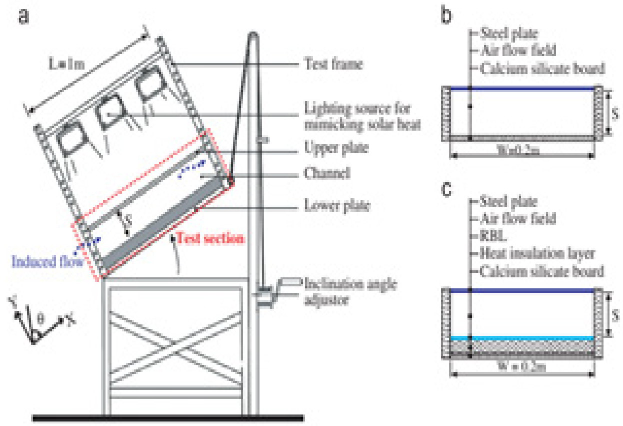


Fig. 28: Experiment facility and test sections; (a) Experiment facility; (b) cross-section view without RBL; (c) cross-section view with RBL [62].

An experimental study (Fig. 29) aimed at reducing thermal gains through the roof, by creating natural ventilation in the lasts, was made by L. Susanti et al [56], these authors affirm that the integration of the cavities of ventilated air in the roofs is effective for the release of the solar gains and it seemed to be effectively applicable to solar incidence discharges in factory buildings.

Fig.29: Cavity model studied by L. Susanti et al [56].

Karim et al [63] conducted a study to investigate the both experimentally and theoretically performance of flat plate, finned and v-corrugated air heaters in an effort to enhance the performance of conventional air heaters. After the close examinations of the performance of all three collectors, the v-corrugated collector was found to be the most efficient and the flat plate was the least efficient one. The results of the test revealed that the v-corrugated collector was 10–10% and 5–11% more efficient under single and double-pass modes, respectively in comparison to flat plate collectors.

One of the main disadvantages of solar thermal air collectors is their relatively low efficiency due to the low density, volumetric heat capacity and thermal conductivity of air causing to low coefficients of convective heat transfer from solar energy to the air [56], So the increase in the exchange surface of the channel may increase the heat transfer to the fluid [64]. For this reason and in order to increase the air flow in the thermosyphon system, we have proposed a sinusoidal shape of the upper plate (hot plate) of a roof solar collector (Fig. 30) [65], we have fined that the use of the corrugated surface gives a flow with a high rate and it allows us to increase the heat transfer to the fluid and the rate of mass flow without affecting the length of the channel.

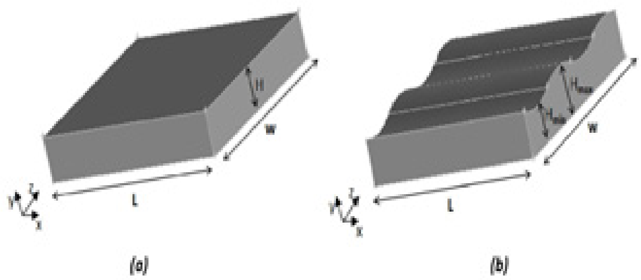


Fig.30: Studied geometries: (a) flat plate channel, (b) channel with sinusoidal upper plate [64].

4.2. Parameters affecting the operation of roof solar collector

Near-optimum efficiency can be easily reached with a 10 cm wide cavity and an inclination angle over 30° from horizontal and the double-skin width must be over 6 cm and under 10 cm [60]. Low thicknesses are recommended to improve the efficiency of these systems [66] where the optimal thickness is 0.07m for 1.36m of length and 0.68m of width [67]. It was also found that a RSC with 14 cm air gap could induce a natural ventilation rate of about 20–100 m3/h depending on the intensity of solar radiation, where the corresponding air change varies between 1 to 4 ACH per unit area with a volume chamber of 25 m3 [61]. Therefore, to maximize the air ventilation by the RSC systems, the length of the RSC should be shorter, in the order of 100–200 cm; this length could be selected by architects, depending on the available surface area of roof [68]. For further designs of RSC systems, the appropriate range of tilt angle should be considered between 20° and 60° [68]. Throw an experimental study J. Khedari et al [69] showed that large air gap and large and equal size of openings would induce the highest rate of air flow rate. Thus, with regard to sizing of the RSC, the thermal capacity of the CPAC Monier tile could also be neglected [68]. On the other hand, Zhai et al [58] has reported that the efficiency of double pass of air gap can induce more air change rate and hence is generally 10% higher than that of single pass roof solar collector. The thermal radiation has a significant effect on the behavior of roof solar collector so it is recommended to consider it in such systems [70] because it has about 30% of total heat exchange in thermosyphon systems [66].

5. Combination of different systems

Building integrated solar thermal collectors may be installed either on the building façade or on the roof causing in each case a different visual impact [71]. The findings from the literature survey have concluded that the combined roof solar collector and vertical stack is a potential solar induced ventilation strategy [56]. So it seems that the combination of the different systems mentioned above can generate large temperature differences. A new strategy was proposed by W.F.M. Yusoff et al [72] which consist of combining a roof solar collector with a vertical chimney (fig. 31). This system has been studied experimentally and theoretically. The results have shown that the proposed solar induced ventilation strategy can improve the ventilation in hot and humid climate. It is able to create air temperature difference of more than the usual air temperature difference attained by naturally ventilated buildings.

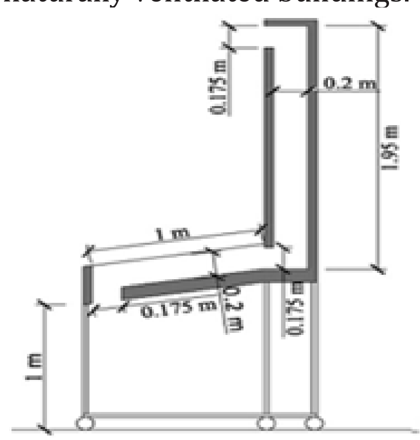


Fig.31: Schematic description of the model proposed by WFM Yusoff et al [72].

Du Wei et al [73] have proposed a series of connected chimneys (Fig. 32) where the inclined section is placed on the roof and the vertical one on the south wall of a typical two-story house. According to them, the optimal width corresponding to the maximal flow rate varied with the total chimney length, the optimal inclined angle was found to be 4°, the vertical section height should be as large as possible, and the ventilation performance was enhanced with the increase of total chimney length. The flow rate inside the chimney decreased with the increase of the length ratio of the inclined section to vertical section.

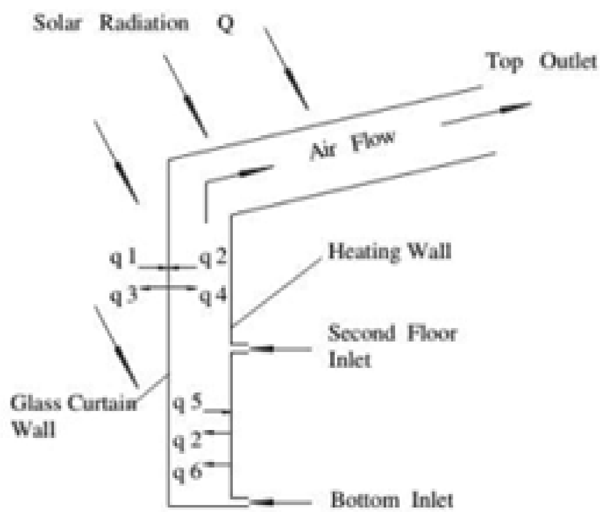
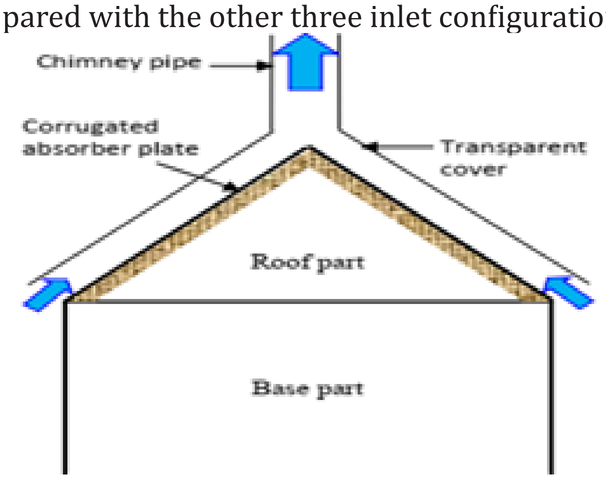


Fig. 32: Schematic configuration of the system proposed by Du Wei et al [73].

The influence of the inlet shape of the solar air collector on the solar chimney performance was investigated experimentally and numerically by Hussain H. Al-Kayiem et al [74], they have found that when the inlet has vertical cross section (Fig. 33), it offered the best performance, velocity and mass flow rate of the air at the chimney was observed to be higher compared with the other three inlet configurations.



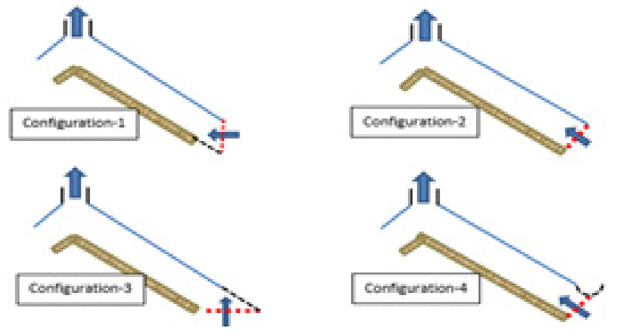


Fig. 33: Four different inlet configurations investigated by Hussain H. Al-Kayiem et al [74].

Joseph Khedari et al [75] have combined two configurations; the roof solar collector (RSC) composed of CPAC Monier concrete tile, 14 cm air gap and gypsum board, and the modified Trombe wall (MTW) composed of a masonry wall, 14 cm air gap and gypsum board (Fig. 34). This system is recommended for air-conditioned residential houses and buildings for both comfort and energy saving. The size of the SC can be adjusted according to the type of house and the intended use.

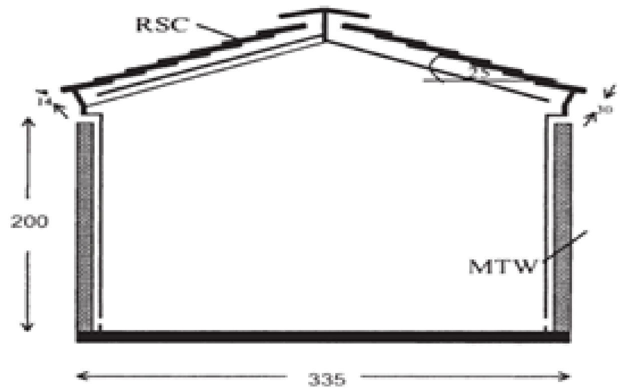


Fig.34: The combined system studied by Joseph Khedari et al [75].

Hussain H. Al-Kayiem et al [76] have presented a Mathematical analysis of the influence of the chimney height and collector area on the performance of a roof top solar chimney (Fig. 35). The analysis was carried out at various collector areas (15, 150, and 600 m2) and various chimney heights (5, 10, and 15 m). The results of this work demonstrated that the performance of the system is highly influenced by the solar intensity. The system becomes functional for space ventilation when the solar intensity is higher than 400 W/m2 with a 15 m2 collector area and 5 m chimney height, under Malaysia and similar weather conditions. As the wind speed increases from 1.5 to 6 m/s, it contributes to reduce the system performance by 25% at solar intensity of 900 W/m2.

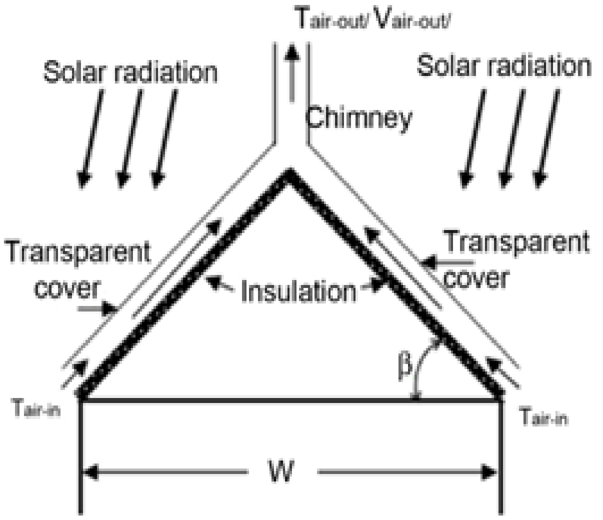


Fig. 35: Schematic view of the system studied by Hussain H. Al-Kayiem et al [76].

A combined solar chimney and water wall (Fig. 36) was proposed by Haoyu Wang and Chengwang Lei [77] to provide moderate ventilation and heating to an attached room, too configurations were tested chimney in front of the water wall (SC-WW, Fig. 36 (b)) and water wall in front of the solar chimney (WW-SC, Fig. 36 (c)). They were studied the effects of the glass panel thickness, air gap width, water column thickness, surface tinting and the relative position of solar chimney and water wall. According to their results this combined system is able to provide ventilation throughout the day and night, air gap width and glass panel thickness have a positive impact on the ventilation rate, the effects of the water column thickness are remarkable in the daytime, and The SC-WW configuration works better than the WW-SC configuration.

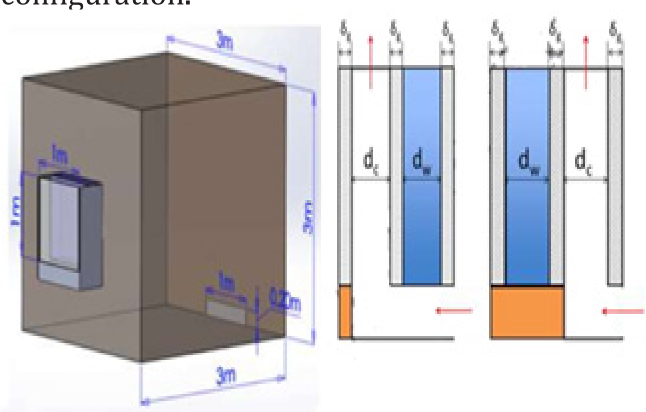


Fig. 36: Schematics of (a) the proposed system with combined solar chimney (SC) and water wall, (b) SC-WW configuration, (c) WW-SC configuration [77].

6. Supply-air window as a passive system

According to thermal regulation (1979) it is mandatory to use double glazing in new buildings and replacing single glazing with double and replacement of frames is a significant energy saving technique for old buildings. Triple glazing is better than double glazing relating to the thermal and insulating abilities [78]. The supply-air window is a passive system of heat recovery contributing to the building ventilation. It allows the air renewal to circulate between glasses before entering the inside environment. Based on this principle, a part of heat transfer through the glasses is recovered by the airflow. The supply air window has shown great potential to perform energy efficiency in building in cold and temperate climate [79]. Double windows as a currently adopted construction system can be changed so that it could be able to pre-heat the ventilation air between the windows. Simple changes consist in introducing vents at the base of the outer window to allow a supply of fresh air. Heat that escapes from inside through the inner window and solar radiation heat up the air between the two windows. Due to wind pressure and stack effect, the air rises and enters the room through a vent at the inside top of the system warmer than the outdoor air [80]. For this reason several studies have shown the performance of the ventilated double window under different climatic conditions as well as the influence of different inputs. Preeda Chantawong et al [81] have proposed a glazed solar wall, this wall consisted of double glass panes with an air layer and openings located at the bottom (room side glass pane) and at the top (ambient side glass pane) (Fig. 37). This system can reduce the heat from the sunlight that gets into the house by improving the air circulation inside the building and let natural sunlight into the house for daytime, it was also economical due to low cost of materials used, it can also reduce the usage of fans due to induced ventilation and reducing demand on electrical energy for air-conditioning. To show how this passive air heating system can be improved in order to collect more solar heat, J.S. Carlos [82] has investigated numerically a ventilated double window (Fig. 38), they found that this component is more advantageous to the thermal balance of the air stream and the use of double ventilated window can improve thermal balance by 8.4% and 12.5%, and increase the delivered air temperature from 9.8 °C to 11.9 °C in Bragança and from 13.5 °C to 17.4 °C in Evora.

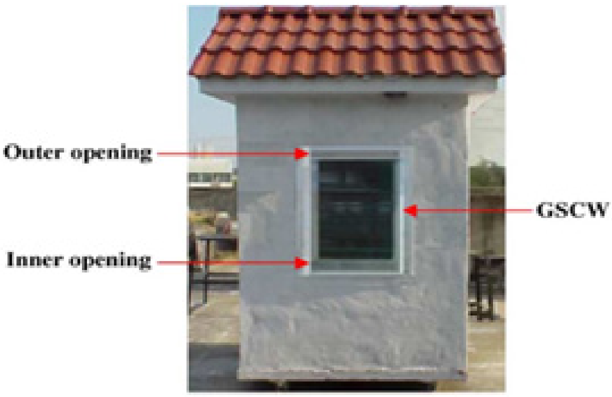


Fig.37: Glazed solar chimney wall [82].

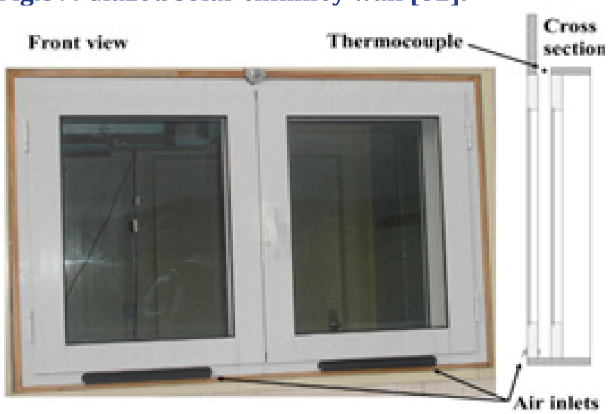


Fig. 38: Ventilated double window studied by J.S. Carlos [82]

In their experimental research, Jaran R and Pithan P [83] have compared popular one-layered glass walls (OLGW) with the double-layered walls or glass solar chimney walls (GSCW) (Fig. 39 (a)), the last one uses the concept of indoor natural ventilation operated by heat transfer to air gap of double-layers glass wall (Fig. 39 (b)). Results the showed that GSCW has good effectiveness for all seasons and it's suitable for tropical climates around the world and can be applied with the green building concept which helps to save energy and the environment because it can reduce the indoor temperature by an average difference of 1.63 – 1.30°C for rainy season, 2.46 – 1.80°C for winter season and 1.36 – 1.28°C for summer season in comparison with the indoor temperature of OLGW. The incorporation of a shade with low emissivity in the air blade (Fig. 40) has an obvious effect on comfort [84, 85].

Throw an experimental study; B. Chen et al [84] show that the optimum distance between the shading and glazing is 23 mm and the convective heat loss is reduced by about 20%.

Fig. 39: OLGW and GSCW house for testing (a), the section of GSCW model (b) [83].

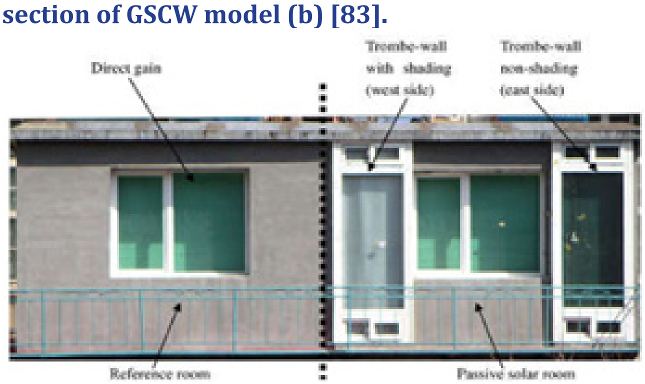


Fig.40: South facade view of the test room (right) and the reference room (left) [84, 85].

7. Conclusion

Different types of solar thermosyphon systems have been discussed in simple manner to attract new researchers in the field of solar air conditioning technology. We have briefly reviewed the advancements in solar thermal technology, and focus especially on thermosyphon systems integrated in buildings and the parameters that can affect its performances. Following concluding remarks may are outlined as follows:

- The integration of such systems with buildings can improve thermal comfort considerably and it is a solution for the economy and the rational use of energy.

- It has been observed that their performance depends essentially on the geometric parameters and the angle inclination. For the solar wall is recommended to increase the width of the air channel and of the vents. The thickness of a solar chimney has a significant impact on its effectiveness but its optimum values depend on other parameter such as length and width, the optimum tilt depend on latitude but 45° is recommended by the majority of research works. Low thicknesses are recommended to improve the efficiency of solar roof collectors.
- The thermal radiation has a significant effect on the behavior of roof solar collector so it is recommended to use of radiant barrier in order to enhance significantly the performance of such systems.
- The environmental parameters, namely, the solar radiation, wind and ambient air temperature highly influenced the performance of the solar induced ventilation.
- Using phase change materials (PCMs) provides an elegant and realistic solution to increase the efficiency of these systems because it can reduce heating and cooling energy in residential buildings by as much as 25% and obtain similar reductions in the power necessary for air conditioning.
- The combination of the different systems can improve the efficiency of natural heating and ventilation.
- Supply-air windows can participate in the amelioration of thermal comfort and reducing the use of supply energy.
- Although research is advanced in this field, it is necessary to make further studies to adapt these systems to climatic conditions and to the altitude of each region.

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