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A review on energy conservation in buildings by use of Air layers and Phase Change Material

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Abstract

Demand for energy has been increasing worldwide and the building sector represents a large percentage of global energy consumption which is directly connected with increasing global warming. In building Heating, Ventilation and Air Conditioning (HVAC) systems are significantly responsible for energy consumption and global warming. To provide suitable quality of air for human comfort, HVAC plays a major role. It is important to see that there is an increasing amount of literature has been published on this topic in recent years. This paper therefore provides an updated review of the literature on energy conservation and performance in residential buildings, by considering the aspects of building envelopes that contain inner air layers and role of phase change material in building energy conservation. The working principle of different air layer used in building envelopes and recent literature on PCM are discussed.

Key Words: *Air Layer, Enery Conservation, Phase Change Materi,; Passive Ventilation.*

INTRODUCTION

Energy consumption in buildings are one of the largest contributors to usage of energy in the present world [1]. Energy utilization in buildings refers to many factors such as lighting, domestic appliances as well as Heating, Ventilation and Air Conditioning (HVAC) systems. As population increases CO_2 emissions will always increase and they will keep on growing. Without considering any further international policies, greenhouse gas (GHG) emissions will rise by 52% from 2005 to 2050 and energy-related carbon dioxide emissions are expected to rise by 78% [2]. Energy in houses is mainly consumed by space heating an ventilation (68.4%) and hot water production (13.6%).The energy used for cooking (3.8%) and electricity for lighting and appliances (14.1%) is far less significant [3]. In current situation the challenge is to focus on conservation of energy of houses by using passive techniques. Among all building applications, HVAC systems play a vital role in building energy consumption [5]. As per data 40% of the energy consumed in office buildings in the EU is used by Heating, Ventilation and Air Conditioning systems [6]. These systems are aerodynamic parts consisting of fans and duct to supply fresh air from the external atmosphere and to remove impure air from the space. In addition to that they can include heat exchangers and humidifiers for controlling the air, mixing chambers to supply fresh air, air filters for cleaning the air, dampers for controlling the flow velocity, and silencers to reduce fan noise. In modern buildings Centralized HVAC systems commonly used and split system air conditioning units are commonly used in older buildings that do not have ventilation ductwork. In recent era HVAC systems have matured technology coupled with the benefits easy flow control.

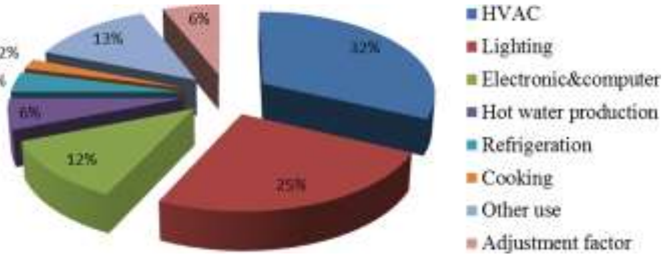

Figure 1. The distribution of energy utilization in a typical commercial building [11].

While searching data bases for other available literature reviews concerning energy efficiency in residential buildings, we found reviews mainly focusing on one specific field in the domain of energy optimization of residential and commercial buildings [7, 8]. Kaynakli [9] reviewed all available literature on determining the optimum thickness of the thermal insulation material of a residential building and its influence on energy demand. More recently, Stevanovic [10] reviewed existing studies on several passive solar design strategies in the case of residential and commercial buildings. The distribution of energy utilization in a typical commercial building as shown in Figure 1[11].

1. LITERATURE REVIEW

1.1 Role of Air layers in building envelopes

Air layer involved envelopes (ALIEs) have gained considerable popularity in modern building design and construction, owing to their great potential in improving the building thermal performance. Basically, the air layer functions as an extra insulation layer or as a ventilation channel. Air layers utilized in external walls.

a. Classic Trombe wall and composite Trombe wall

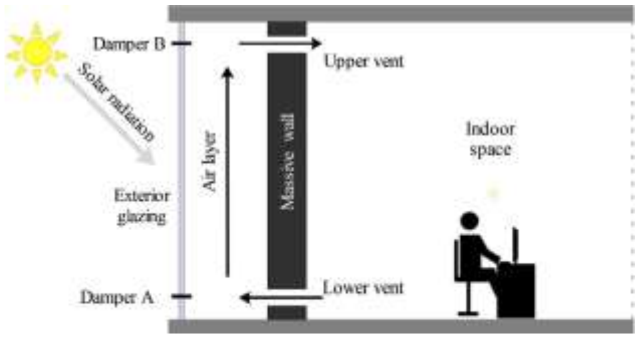

Figure.2 Schematic diagram of classical Trombe wall.

The starting point of the Trombe wall is to absorb solar ray and convert its energy for heating, ventilating so as to provide thermal comfort in buildings [12]. Edward Morse, an American engineer, designed and patented the Trombe wall in 1881. But the concept was popularized by Felix Trombe and Jacque Michel in France, therefore, it is well known as the Trombe wall [13]. The Trombe wall mainly consists of a massive wall, an exterior glazing cover, and an air channel between the massive wall and the cover (FIG 2). The massive wall is used for absorbing and storing the solar energy that passes through the glazing cover. The massive wall must be constructed with high heat-storage capacity materials, including bricks, concrete, stone and adobe, and the external surface of the massive wall is usually colored black in order to increase the solar absorption [14, 15]. The thickness of the air channel ranges from 3 cm to 6 cm [16]. Part of the absorbed energy is transferred to the indoor space through heat convection, conduction and radiation between the massive wall and room air; the rest part is also transported to the indoor space by air circulation, in which low temperature air from the room enters the internal channel through the lower vent, gets heated by the massive wall and flows upward due to buoyancy effect, and then returns to the indoor space through the upper vent of the wall with a higher temperature [12]. The heat stored in the massive wall releases gradually through radiation and convection to increase thermal comfort.

b. Ventilated or double-skin glazing facades

The concept of double-skin façades (DSF) was firstly proposed in early 1900s, but it had been progressed little until the 1990s [17]. The DSF is now becoming a popular architectural element on the premise that more and more transparent façades are employed in modern office buildings, and building energy efficiency becomes a critical point of global energy utilization.

Double-skin façade is defined as a special type of exterior building envelope, which is composed of an external façade layer, an interior façade layer and an air layer in between. The external layer, usually a hardened single layer of float glass or safety glass, provides protection against the outdoor condition and extra acoustic insulation against external noise; while the interior layer often consists of double-pane glasses. The width of the air space between the two skins, named the air channel, ranges from 200 mm to more than 2 m. usually, an adjustable sun shading system is installed in the air channel for controlling solar radiation [18]. The DSF can work either in an air-fixed mode or an air ventilated mode. The air-fixed mode provides extra thermal insulation for external envelopes to reduce heat transfer in winter.

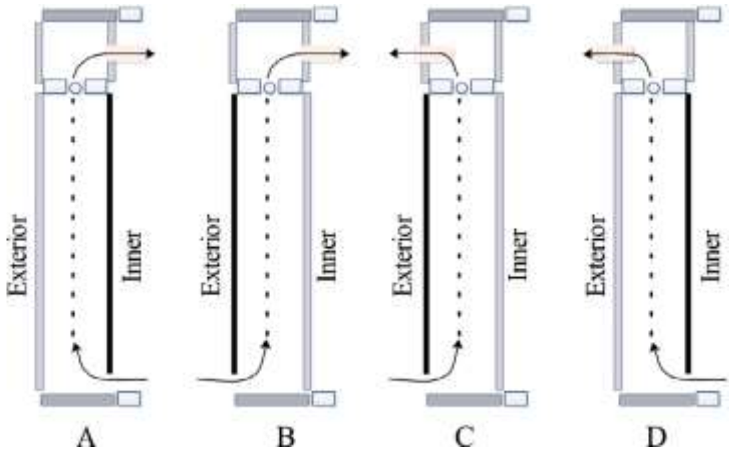

Figure 3. Schematic of the working modes of double-skin façade: A – inner circulation mode; B – supply mode; C – inner circulation mode; D – exhaust mode.

The air-ventilated mode deals with overheating problems in summer and helps to achieve energy savings in winter. The driving force of the air ventilation in the channel of DSF could be natural, mechanical or a mixed of them. Both the wind pressure and the thermal buoyancy effect produced by the temperature difference between the exterior and interior façades can give rise to natural air ventilation in the channel [19]. The mechanical ventilation employs some power machines to generate air flows in the cavity, while the mixed ventilation results from a combination of natural force and mechanical force. According to the different air flow paths, the ventilation working modes of a DSF can be classified into four types, as shown in Figure. 3.

c. Wall-based solar chimney

The solar chimney technology, which offers an excellent natural ventilation opportunity for buildings, is now receiving increasing concern as a large amount of energy has been spent on building ventilation and air-conditioning and substantial greenhouse gas has been released due to the ventilation purpose. Recently, a number of theoretical, numerical and experimental studies have been conducted to demonstrate the ventilation performance of the solar chimney and have contributed significantly to the practical application of this technology [20]. Solar chimney utilizes solar radiation to induce a thermal buoyancy effect, thus enhancing the natural ventilation for a building. When the solar energy is absorbed, the air temperature rises and the air density drops in the air channel of the solar chimney, which makes the air to move upward and finally the heated air is discharged from the top of the chimney [21]. There are two different configurations of the solar chimneys, the vertical solar chimney and the inclined solar chimney [23]. The former employs wall solar collectors, while the latter adopts roof solar collectors. A solar chimney typically consists of an air channel, an absorbing wall and a glass cover with high solar transmissivity to maximize the solar gain so as to enhance the chimney effect. Moreover, the glass cover may be constructed integrated with photovoltaic cells or be substituted by other opaque covers in some cases. The vertical solar chimney is usually attached to the external wall of a building, in which a vertical air channel is structured with a rectangular cross section [22]. The outer side of the channel is made of a glass cover, while the inner side is made by opaque and absorbing wall materials to absorb solar radiation (Figure. 4).

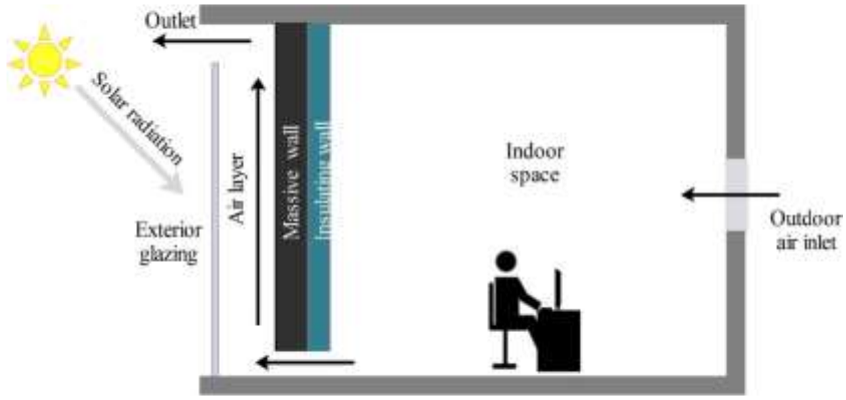

Figure. 4. Schematic of a wall-based solar chimney.

Air enters the chimney channel from the bottom of a room requiring to be ventilated. The opaque absorbing wall captures most of the solar radiation and increases its surface temperature. Subsequently, the internal air of the channel is heated by the absorbing wall surface through natural heat convection. As a result of the air density decrease caused by the temperature increase, a natural ascending flow is generated. The heated air finally reaches the top outlet of the chimney is then discharged to the atmosphere. The absorbing wall is insulated at the backside to reduce the heat transfer from the heated surface toward the internal room space.

d. Glazed and unglazed transpired solar walls

Transpired solar collectors can be integrated to building external envelopes to obtain heating and ventilation profits in cold areas. The technology has been widely used in USA and Canada, where transpired solar collectors are served as high-efficiency fresh air preheating systems [25]. According to their working properties, they can be classified as unglazed transpired collectors (UTC) and glazed transpired collectors (UTC) [24]. UTC was introduced in the early 1990s for the purpose of using solar energy for ventilation and warm air heating [26]. The UTC is a wall based heating system which employs a perforated metal sheet as a solar absorber to warm the fresh air. This UTC is also named as the Unglazed Solar wall. The schematic diagram of the UTC is illustrated in Fig.5. The absorber surface is generally constructed from perforated metal plate (steel or aluminum) and covered with a proper coating. The absorber plate is usually integrated to the external wall of a building. With the help of a ventilation fan, the outdoor air is drawn through the perforations of transpired metal plate into the internal cavity, and simultaneously the air is heated up. The warmed air is finally supplied into the indoor space. In hot weather conditions, the warmed air is directly released to the ambient through the discharge valve located at the top of the cavity to avoid over heating of the indoor air, or it can be used for other purpose such as hot water production to make full use of the UTC system. Which means that the UTC system did not work at all actually as require indoor temperature is higher than required temperature. That is, the solar fraction of the system is zero.

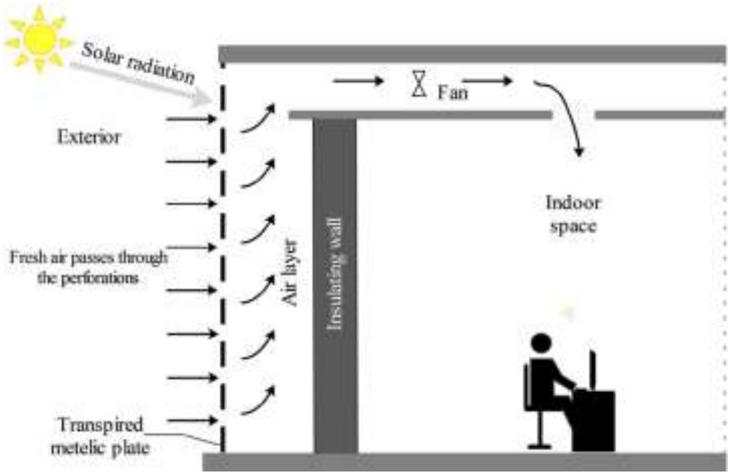

Figure. 5. Schematic diagram for unglazed transpired collector.

To solve the above mentioned conflict, the GTC is introduced [28]. Compared with the UTC, a glazing cover is added, and relevant air vents are placed on the cover. The configuration of GTC is illustrated in Fig.6. The transpired absorber plate is constructed from metal plate with uniform-distributed holes, which is perforated and covered with selective coating, and is mounted out 100–200 mm from the back wall surface, and the distance between the absorber plate and the glazing cover is 100–200 mm. Fan draws the outdoor fresh air into the outer cavity between the glazing and the absorber plate, and then through the transpired absorber plate into the inner cavity between the transpired absorber plate and the back plate, and at last into the indoor space that need to be heated through air ducts. With the promotion of the solar energy absorbed by the metal plate, air is heated when it is drawn through the small holes on the absorber plate. At night time, the air inlet and the fan are closed to form an enclosed cavity in the solar wall structure. The heat loss of the external wall is absorbed by the internal air of the enclosed cavity, which offers an air insulation layer for the external envelopes. Additionally, the adverse effect of crosswinds could be eliminated as the absorber surface is isolated from the ambient by the glazing cover.

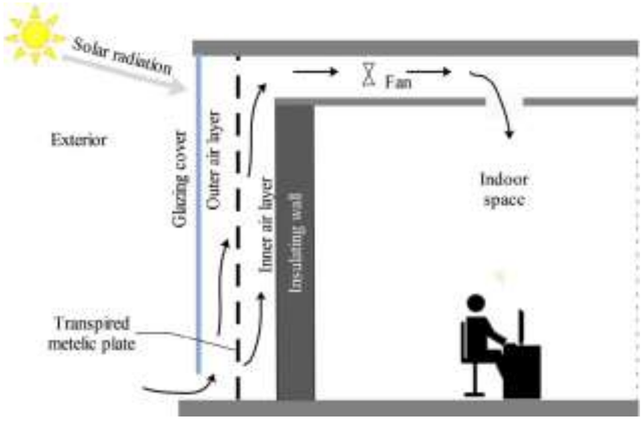

Figure 6. Schematic diagram for glazed transpired collector

e. Ventilated PV facades

Photovoltaic (PV) cells/modules are nowadays widely used in buildings for the electricity generating capacity from solar radiation [29]. A building integrated photovoltaic/thermal (BIPVT) system which combines building envelopes and photovoltaic (PV) modules, can not only generate electricity in situ, but also reduce the heating load in winter and cooling load in summer for a building's air-conditioning system There are mainly two application methods to construct a DSF based BIPVT system, one is suitable for new buildings, which uses PV modules to replace the external façade of a DSF system in the external envelope directly to constitute a BIPVT system; while the other is suitable for energy-saving reconstruction work for existing buildings, in which the PV modules are added on existing external walls or glass curtain walls to form a BIPVT system. Thus, in all air layer involved external wall systems mentioned in the previous sections, including the Trombe walls, the DSF façades, the wall based solar chimneys, and the solar wall systems, opaque or semi-transparent PV modules can substitute the external façade layer to obtain electricity generation capacity. The electrical efficiency of PV cells was tested to be in the range from 6% to 18%, which is affected greatly by the operating temperatures. When the operating temperature rises, the efficiency falls. Every 1 K increase in operating temperature results in a 0.25% efficiency decline for the amorphous silicon PV cells [29] and around 0.4–0.5% for the crystalline silicon PV cells [30]. Thus it is essential to remove the accumulated heat from the PV cell for the purpose of increasing the electrical efficiency.

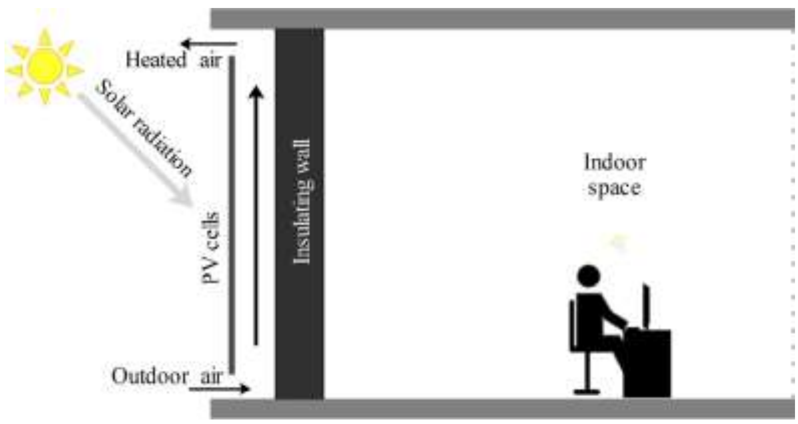

Figure 7. Schematic diagram of passive ventilated PV facade.

There is other such arrangement in exterior walls such as indirect vertical greenery walls/double-skin green façades and Double layer walls/hollow masonry walls. The arrangements can be incorporated in windows and roof top.

TABLE 1. Summary on the performances of different types of air layer involved envelopes.

Envelope designs	Structure (from outside	Airflow pattern	Effect of air layer	System functions and benefits	Restrictions and disadvantages
Classic Trombe wall	Exterior glazing, air layer, storage wall	Enclosed air layer inwinter night; naturally ventilated in	Winter night: Insulation layer; winter mode: thermal transfer medium for space heating and fresh air channel; Summer mode: natural ventilation channel	Winter mode: space heating and fresh airn supplying: summer mode: passive cooling of the building	Only applicable in winter in cold climates; during summer, excessive heat gain may occur; increase
Double-skin glazing façade	External façade layer, air layer, interior façade	Enclosed/naturally ventilated/mechanically ventilated I different working	Insulation layer in air-fixed mode: Heat removal medium in external respiration mode; fresh air channel and natural ventilation channel in other modes	Air-fixed mode provides extra thermal insulation for external envelopes; Air-ventilated mode deals with overheating problems in	Pretty high initial cost and maintenance cost, usually used in slap up commercial buildings;
Wall-based solar	Exterior glazing, ventilated air	Natural ventilated	Absorb heat from the absorbing wall and act as the driving force of the natural ventilation, space heating or external	Mainly used as a natural ventilation system in summer; sometimes served as space heating system and	Applicable in moderate climates and hot climates; increase initial
Unglazed transpired solar wall	Transpired plate, air layer, wall façade	Mechanically ventilated	Absorb heat from the transpired plate and act as thermal transfer medium for space heating; the air source for fresh air supplying	Only for space heating and fresh air supplying in winter	Applicable in moderate climate; increase initial cost of external walls; system performance I
Glazed transpired solar wall	Exterior glazing, outer air layer, transpired	Enclosed or mechanically ventilated	Insulation layer in the off-mode; Absorb heat from the transpired plate and act as thermal transfer medium for space heating; the air source for fresh air	Only for space heating and fresh air supplying in winter in the daytime; Served as an insulation air layer at non-sunshine time	Applicable in cold and severe cold climates; increase initial cost of external walls; fan make
Ventilated PV façade	PV panel, air layer, wall façade	Naturally or mechanically ventilated	Absorb heat from PV panel to increase the electricity efficiency; Take away the accumulated heat an reduce the cooling load in summer; The air source for fresh air supplying and space heating in winter	Used for electricity generating all year around; Used for space heating and/or fresh air supplying in winter; Used for passive cooling to reduce cooling load in summer	Reduce heat gain through building boundary; increase initial cost of external walls
Double-skin green façade	Plant layer, air layer, wall façade	Natural ventilated	Acts as a thermal buffer and reduces the heat gain through external envelope	Used as a passive cooling system to reduce ambient air temperature, exterior surface temperature, interior air temperature and heat	Usually used in hot climates; extremely high initial cost of external walls; hard to
Hollow masonry wall	Exterior masonry layer, air layer, inner	Enclosed, naturally ventilated,	As an insulation layer in enclosed mode; Remove the heat from the exterior layer to reduce cooling load in summer	Used as a low heat transfer coefficient external wall or as a passive/active cooling strategy	Used in medium and low-rise buildings; increase initial cost of external

1.2 Review on Phase Change Material

Therefore, the impact of cooling systems cannot be ignored, as they, along with ventilation and heating systems, account for 60% of the energy consumed in buildings. Passive cooling techniques are a promising alternative to conventional cooling systems. Of the various passive cooling strategies, thermal energy storage by means of latent heat is an efficient way to increase the thermal inertia of building envelopes, which would reduce temperature fluctuations, leading to the improved thermal comfort of occupants. Phase change materials (PCMs) with high density for thermal energy storage can be efficiently employed to this purpose.

Thermal energy storage (TES) systems store energy in thermal form for utilization at a later time. Broadly, TES systems involve three main steps: thermal charging, thermal storing and thermal discharging [31]. Materials can reserve heat in three primary ways, including sensible heat, latent heat and chemical reactions.

a. Phase change material classifications

Changing of material phase can be classified into four states: solid–solid, solid–liquid, gas–solid and gas–liquid. For practical purposes, only the solid–liquid variety can be used for building cooling or heating because the other varieties have technical limitations [34, 35]. There is a wide variety of PCMs on the market with different melting point ranges .The most common classifications of PCMs are organic, inorganic and eutectic [36,37], as presented in Fig. 8 and discussed in detail in the following sections.

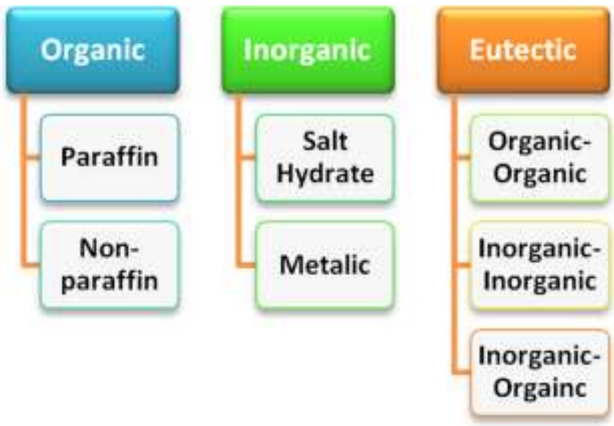

Figure. 8. Different types of PCMs [38].

b. Organic phase change materials

Even though organic PCMs cover a wide range, pure n-alkanes, fatty acids and esters are the most well-known for latent heat storage [39]. Organic PCMs have drawn attention because of their additional latent heat capacity, appropriate phase-transition temperature and stable physical and chemical characteristics. Pure organic PCMs demonstrate some short comings that limit their usage in practice, including low thermal conductivity (usually less than 0.2W/m2 K for organic PCMs [40]), high volume variation and liquid see page during state changes [41]. Organic PCMs are classified as paraffin or non-paraffin. Organic PCMs usually do not display corrosive characteristics and have congruent melting. The melting point and heat of fusion of some organic PCMs suitable for building applications are presented in TABLE 2.

Table 2 : Latent heat and melting points of some organic PCMs (including paraffin and fatty acids) suitable for cooling in buildings [42-44].

No	Material	Melting point(°C)	Latent heat (kJ/kg)
1	Glycerin	17.9	198.7
2	Paraffin C16	18.2	238
3	Butyl stearate	19	140
4	Propyl palmitate	19	186
5	Butyl stearate	19	140
6	Propyl palmitate	19	186
7	Emerest 2325	20	134
8	Emerest 2326	20	139
9	Lithium chloride ethanolate	21	188
10	Dimethyl sabacate	21	135
11	Paraffin C17	21.7	213
12	RT20	22	172
13	Polyglycol E600	22	172.2

14	D-Lattic acid	26	184
15	MICRONAL26	26	110
16	MICRONAL 5001	26	110
17	1-dodecanol	26	100
18	Octadecyl thioglyate	26	90
19	n-Octadecane	27	243.5
20	Paraffin C18	28	244
21	Methyl palmitate	29	215
22	Acid Methyl pentacosane	29	197
23	Methyl palmitate	29	205
24	Capric acid	29.6	139.8
25	ERMEST2325	20	138
26	Heptadecane	21.8	172
27	Polyethylene glycol 600	23	146
28	Paraffin C13–C24	23	189
29	RT27	27	179
30	Vinyl stearate	28	122

c. Inorganic phase change materials

Comparing to organic PCMs, inorganic PCM shave higher heat of fusion per unit mass with lower cost and flammability (usually). However, they do suffer from super cooling phase segregation, lack of thermal stability, corrosion and decomposition, which over shadows their advantages [45]. This category includes salt hydrates, salt solutions and metals [46], however, salt hydrates are the most well-known variety and numerous studies have used them for thermal storage applications. Table 3 summarizes the latent heat and melting points of several inorganic PCMs. The attractiveness of salt hydrates for heat storage purposes in buildings is due to their considerable volumetric storage density (350 MJ/m^3), high thermal conductivity.

Table 3 .Latent heat and melting points of some salt hydrates [45-47].

No	Material	Melting point (°C)	Latent heat (kJ/kg)
1	$KF.4H_2O$	18.5	231
2	$K_2HPO4\ .4H_2O$	18.5	231
3	$FeBr_3\ .6H_2O$	21	105
4	$Mn(NO_3)_2.6H_2O$	25.5	148
5	$LiBO_2.8H_2O$	25.7	289
6	$FeBr_3\ .6H_2O$	27	105
7	$CaCl_2.6H_2O$	29	191
8	$CaCl_2.12H_2O$	29.8	174
9	$LiNO_3.2H_2O$	30	296
10	$LiNO_3.3H_2O$	30	189

d. Eutectics

Eutectic PCMs consist of a combination of at least two other PCMs. During the freezing process they form a blend crystal [48]. This mixture can consist of inorganic with inorganic, organic with inorganic and organic with organic (Table 3) [47]. The separation of the components is very unlikely because they mostly change phase without segregation (due to freezing to an intimate crystal mixture) and during the melting process all components change to liquid simultaneously. Some of the common eutectic PCMs that can be employed for passive cooling in buildings are shown in Table 4.

Table 4. Latent heat and melting points of a selection of eutectic PCMs [45-47].

No	Material	Melting point (°C)	Latent heat (kJ/kg)
1	Capric + lauric acid	21	143
2	Capric + myrstic	21.4	152
3	Capric + palmitate	22.1	153
4	Methyl stearate + cetyl stearate	22.2	180

5	Capric acid+ myristic acid	22.6	154.8
6	Methyl stearate +methyl palmitate	23.9	220
7	$C_{14}H_{28}O_2+C_{10}H_{20}O_2$	24	147.7
8	$Na_2S_4+MgSO_4+H_2O$	24	na
9	$C_{14}H_{28}O_2+C_{10}H_{20}O_2$	24	147.7
10	Tetradodecanol+ lauric acid	24.5	90
11	Capric acid+ stearic acid	24.7	178.6
12	$CaCl_2+MgCl_2 .6H_2O$	25	95
13	$CaCl_2. 6H_2O$+Nucleat+$MgCl_2 .6H_2O$	25	127
14	Capric+ stearate	26.8	160
15	$CH_3CONH_2+NH_2CONH_2$	27	163
16	Methyl stearate+ cetyl palmitate	28.3	189
17	Triethylolethane+ urea	29.8	218
18	$Ca(NO_3) .4H_2O+ Mg(NO_3)_3 .6H_2O$	30	126
19	$CH_3COONa .3H_2O+ NH_2CONH_2$	30	200.5
20	$CaCl_2$+ NaCl+ KCl+ H_2O	27	188

e. Selection criteria for PCMs for passive cooling of buildings

PCMs can reduce the energy needs of cooling systems and indoor temperature fluctuations, however, for PCMs to be effectively implemented for passive cooling in the building envelope, several selection criteria must be considered .From a physical point of view, the melting point of the PCM should be in the range of 10 °C to30°C to provide thermal comfort for occupants. This temperature should be selected with respect to average day and night temperatures and other climatic conditions of the building site [49].

Thermodynamically, the PCM should have high latent heat per volume unit, which is an important factor in building applications because it means that with lower volume, the PCM can absorb/ release higher amounts of energy leading to a lighter building envelope [50]. Moreover, it should also have a large specific heat capacity (Cp) .

Another significant thermodynamic factor is its heat transfer ability (conductivity).Higher conductivity results in faster thermal responses. Even though the thermodynamic properties are the main selection criteria for the use of a PCM, other important properties are related to its chemical aspects, including chemical stability, low volume expansion and low/no super-cooling during freezing; it is also important for PCMs to be non-toxic, non-corrosive, non-flammable and non-explosive [49-50].

Furthermore, a PCM is suitable for applications if it is stable after a number of repeated melting/freezing cycles, that is, if it has a proper cycling stability. This is also called long-term stability [51]. Low thermal conductivity is considered to be the main problem for most PCMs and can be a serious challenge for the application of PCMs as passive cooling systems. There are three main techniques to improve thermal conductivity:

- The first technique is to make a composite of PCM with porous metal foam or expanded graphite matrices [51].
- The second technique is to add metallic spheres, screens, fins and wools to develop a new thermal conductivity enhanced material [51].
- The final method is the application of Nano materials. Nano- particles are capable of enhancing micro convection; therefore, the application of Nano-particles can improve the heat transfer significantly. Nano-materials that can be used for this purpose include carbon in various forms(carbon nanotubes),stable metals (e.g. Gold and copper),oxide ceramics(e.g.,Al2O3 and Cu O), metal oxide(e.g. Silica, alumina and zirconia),oxide ceramics (e.g.,Al2O3 and CuO),metal nitrides(e.g., AIN and SiN) and metal carbides(e.g.,SiC) [52].

In summary, the physical requirements for a PCM are to have a suitable phase change temperature, a completely reversible freeze/melt cycle, a large change in enthalpy (ΔH), a large specific heat capacity (C_p), a large thermal conductivity (k) and little sub-cooling. The chemical requirements are small volume pressure, low vapor pressure, good compatibility with other materials, chemical stability, physical stability and non-toxicity. The economic requirements are low price and being recyclable and abundant.

CONCLUSIONS

This paper presents a literature review on building envelopes that contain inner air layers and phase change material. The operation modes of the air layer used in building envelopes are roughly classified into three types: the enclosed type, the naturally ventilated type and the mechanically ventilated type. The enclosed type acts as an extra insulation layer; the naturally ventilated air layer is often adopted in passive cooling systems and some of the space heating systems; and the mechanically ventilated type is applied in space heating systems or the ventilated façades in which the flow resistance is larger than the buoyance effect. PCM is a powerful alternative to conventional cooling systems. PCM, which employs the latent heat storage concept, can act as a smart material to control the indoor environment of a building. In this study, it was found that the organic type (particularly paraffin) drew the most attention from scholars owing to its appropriate characteristics, such as reasonable price, stability, and non-corrosively and high heat of fusion. However, paraffin suffers from low thermal conductivity. Even though other types of PCM, such as salt hydrates, demonstrated suitable properties, their application was found to be limited. For each type of PCM, a list of those that can be potentially utilized for passive cooling in buildings was presented in this study. In general, there are two techniques for PCM operation in buildings: active and passive. In the active technique, the PCM is charged by a conventional cooling system and discharged during the day time to cool the indoor environment. In its passive form, the temperature difference between night and day cause the charging and discharging processes.

REFERENCE

[1] Tofield B, Ingham M. Refurbishing Europe—an EU strategy for energy efficiency and climate action led by building refurbishment Build with CaRe , Norwich 2012.

[2] OECD. Climate change: meeting the challenge to 2050. Retrieved 25.08.16, from OECD: 2008.

[3] EEA. Energy consumption by end uses per dwelling. Retrieved 25.08.16, from EEA: 2014.

[4] European Union. Proposal for a Directive on the energy performance of buildings .Retrieved 24.08.16, from ⟨http://eur-lex.europa.eu/resource.html?uri=cellar:59e9eb66-8a4d-451e-99f8-71b0a6d6ae28. 0002.03/DOC_1&format=PDF⟩; 2008.

[5] Cao G, Awbi H, Yao R, Fan Y, Sirén K, Kosonen R,A review of the performance of different ventilation and air flow distribution systems in buildings. Build Environ 2014;73:171–86.

[6] Jamaludin AA, Hussein H, Mohd Ariffin AR, Keumala N. A study on different natural ventilation approaches at a residential college building with the internal court yard arrangement. Energy Build 2014;72:340–52.

[7] Evins R .A review of computational optimisation methods applied to sustainable building design. Renew Sustain Energy Rev 2013;22:230–45.

[8] Harvey L D D. Recent advances in sustainable buildings: review of the energy and cost performance of the state-of-the-art best practices from around the world. In: Gadgil A, Liverman DM, editors. Annual review of environment and resources, vol.38; 2013.p.281–309.

[9] Kaynakli O. A review of the economical and optimum thermal insulation thickness for building applications. Renew Sustain Energy Rev 2012; 16:415–25.

[10] Stevanović S. Optimization of passive solar design strategies: are view. Renew Sustain Energy Rev 2013; 25:177–96.

[11] Tiantian Zhang , Yufei Tan , Hongxing Yang , Xuedan Zhang The application of air layers in building envelopes: A review Applied Energy 165 (2016) 707–734

[12] Zamora B, Kaiser AS. Thermal and dynamic optimization of the convective flow in Trombe Wall shaped channels by numerical investigation. Heat Mass Transf 2009;45(11):1393–407.

[13] Saadatian O, Sopian K, Lim CH, et al. Trombe walls: a review of opportunities and challenges in research and development. Renew Sustain Energy Rev 2012;16(8):6340–51.

[14]NREL. Building a better Trombe wall. Colorado: Department of Energy's premier laboratory for renewable energy & energy efficiency research, development and deployment; 2012.

[15] Shen J, Lassue S, Zalewski L, et al. Numerical study on thermal behavior of classical or composite Trombe solar walls. Energy Build 2007; 39(8):962–74.

[16] Torcellini P, Pless S. Trombe walls in low-energy buildings: practical experiences. Colorado: Department of Energy Office of Energy Efficiency and Renewable Energy by Midwest Research Institut; 2004.

[17] Pomponi F, Ip DK, Piroozfar DP. Assessment of double skin façade technologies for office refurbishments in the United Kingdom. Verlag Der Technischen Universität Graz; 2013.

[18]Baldinelli G. Double skin façades for warm climate regions: Analysis of a solution with an integrated movable shading system. Build Environ 2009; 44 (6):1107–18.

[19] Gratia E, Herde AD. Guidelines for improving natural daytime ventilation in an office building with a double-skin facade. Sol Energy 2007; 81 (4):435–48.

[20] Khanal R, Lei C. A numerical investigation of buoyancy induced turbulent air flow in an inclined passive wall solar chimney for natural ventilation. Energy Build 2015;93:217–26.

[21] Lee KH, Strand RK. Enhancement of natural ventilation in buildings using a thermal chimney. Energy Build 2009;41(6):615–21.

[22] Suárez-López MJ, Blanco-Marigorta AM, Pistono-Favero J, et al. Numerical simulation and exergetic analysis of building ventilation solar chimneys. Energy Convers Manage 2015;96:1–11.

[23] Zhai XQ, Song ZP, Wang RZ. A review for the applications of solar chimneys in buildings. Renew Sustain Energy Rev 2011;15(8):3757–67.

[24] Shukla A, Dan NN, Cho YJ, et al. A state of art review on the performance of transpired solar collector. Renew Sustain Energy Rev 2012;16(6):3975–85.

[25] Saxena A, Varun, El-Sebaii AA. A thermodynamic review of solar air heaters. Renew Sustain Energy Rev 2015;43:863–90.

[26] Bellia L, Marino C, Minichiello F, et al. An overview on solar shading systems for buildings. Energy Procedia 2014;62:309–17.

[28] Gao L, Hua B, Mao S. Potential application of glazed transpired collectors to space heating in cold climates. Energy Convers Manage 2014;77(1):690–9.

[29] Zhang X, Zhao X, Smith S, et al. Review of R&D progress and practical application of the solar photovoltaic/thermal (PV/T) technologies. Renew Sustain Energy Rev 2012;16(1):599–617.

[30] Peng J, Lu L, Yang H, et al. Validation of the Sandia model with indoor and outdoor measurements for semi-transparent amorphous silicon PV modules. Renewable Energy 2015;80:316–23.

[31]CabezaL F, Gutierrez A, Barreneche C, Ushak S, Fernández Á G, Inés Fernádez A, etal . Lithium in thermal energy storage: a state-of-the-art review. Renew Sustain Energy Rev 2015;42:1106–12.

[32]Pintaldi S, Perfumo C, Sethu venkatraman S, White S, Rosengarten G. A review of thermal energy storage technologies and control approaches for solar cooling. Renew Sustain EnergyRev2015;41:975–95.

[33] Hesaraki A, Holmberg S, Haghighat F. Seasonal thermal energy storage with heat pumps and low temperatures in building projects—a comparative review. Renew Sustain Energy Rev 2015;43:1199–213.

[34]Sun X, Zhang Q, Medina MA, LeeK O. Experimental observations on the heat transfer enhancement caused by natural convection during melting of solid– liquid phase change materials (PCMs). Appl Energy 2016;162:1453–61.

[35] Qian T, LiJ, Min X, Deng Y, Guan W, Ning L. Diatomite: a promising natural candidate as carrier material for low, middle and high temperature phase change material. Energy Convers Manage 2015;98:34–45.

[36]Anisur MRR, Mahfuz MHH, Kibria MAA, Saidur R. Metselaar IHSCHSC, Mahlia T M I M I. Curbing global warming with phase change materials for energy storage. Renew Sustaine Energy Rev 2013;18:23–30.

[37] Cao L, Su D, Tang Y, Fang G, Tang F. Properties evaluation and applications of thermal energy storage materials in buildings. Renew Sustain Energy Rev 2015;48:500–22.

[38] Zhou D, Zhao C Y, Tian Y. Review on thermal energy storage with phase change materials (PCMs) in building applications. Appl Energy 2012;92:593– 605.

[39] Kenisarin MM. Thermo physical properties of some organic phase change materials for latent heat storage. A review. Sol Energy 2014;107:553–75.

[40] Fang X, Fan L-W, Ding Q, Yao X-L, Wu Y-Y, Hou J-F, etal. Thermal energy storage performance of paraffin based composite phase change materials filled with hexagonal boron nitride nano sheets. Energy Convers Manag 2014;80:103–9.

[41] Mehrali M, Tahan Latibari S, Mehrali M, Mahlia TMI, Sadeghinezhad E, Metselaar HSC. Preparation of nitrogen-doped grapheme/palmitic acid shape stabilized composite phase change material with remarkable thermal properties for thermal energy storage. Appl Energy 2014;135:339–49.

[42]Yuan Y, Zhang N, Tao W, Cao X, He Y. Fatty acids as phase change materials: a review. Renew Sustain Energy Rev2014;29:482–98.

[43] Waqas A, Ud Din Z. Phase change material (PCM) storage for free cooling of buildings—a review. Renew Sustain Energy Rev 2013;18:607–25.

[44] Su W, Darkwa J, Kokogiannakis G. Review of solid liquid phase change materials and their encapsulation technologies. Renew Sustain Energy Rev 2015;48:373–91.

[45] Fauzi H, Metselaar HSC, Mahlia TMI, Silakhori M. Sodium laurate enhancements the thermal properties and thermal conductivity of eutectic fatty acid as phase change material (PCM).Sol Energy2014;102:333–7.

[46] Ferrer G, Solé A, Barreneche C, Martorell I, CabezaL F. Review on the methodology used in thermal stability characterization of phase change materials. Renew Sustain Energy Rev2015;50:665–85.

[47] Tatsidjodoung P, Le Pierrès N, LuoL. A review of potential materials for thermal energy storage in building applications .Renew Sustain Energy Rev 2013;18:327–49.

[48]Osterman E, Tyagi VV, Butala V, Rahim NA, Stritih U. RevIEW of PCM based cooling technologies for buildings, 49;2012.p.37–49.

[49] Sarı A. Composites of polyethylene glycol (PEG600) with gypsum and natural clay as new kinds of building PCMs for low temperature-thermal energy storage. Energy Build2014;69:184–92.

[50] Barreneche C, NavarroH, Serrano S, Cabeza LF, Fernández AI. Newdatabase on phase change materials for thermal energy storage in buildings to help PCM selection. Energy Procedia2014;57:2408–15.

[51] Tiago Silva n, Romeu Vicente, Fernanda Rodrigues Literature review on the use of phase change materials in glazing and shading solutions Renewable and Sustainable Energy Reviews 53(2016)515–535

[52] Farah Souayfane, Farouk Fardoun, Pascal-Henry Biwole, Phase Change Materials (PCM) for cooling applications in buildings: A review, Energy and Buildings

[53] Ascione F,Bianco N, DeMasi RF, de' Rossi F,Vanoli GP. Energy refurbishment of existing buildings through the use of phase change materials: energy savings and indoor comfort in the cooling season. Appl Energy 2014;113:990–1007.

[54] Jaworski M, Łapka P, Furmański P. Numerical modelling and experimental studies of thermal behaviour of building integrated thermal energy storage unit in a form of a ceiling panel. Appl Energy2014;113:548–57.

[55] Royon L, Karim L, Bontemps A. Optimization of PCM embedded in a floor panel developed for thermal management of the light weight envelope of buildings. Energy Build 2014;82:385–90.

[56] Borderon J, Virgone J, Cantin R. Modeling and simulation of a phase change material system for improving summer comfort indomestic residence. Appl Energy 2015;140:288–96.

[57] Memon SA, Cui HZ, Zhang H, Xing F. Utilization of macro encapsulated phase change materials for the development of thermal energy storage and structural light weight aggregate concrete. Appl Energy2015;139:43–55.

[58] Zhong K, Li S, Sun G, Li S, Zhang X. Simulation study on dynamic heat transfer performance of PCM-filled glass window with different thermo physical parameters of phase change material. Energy Build 2015.

[59] Tokuç A, Başaran T, Yesügey SC. An experimental and numerical investigation on the use of phase change materials in building elements: the case of a flat roof inIstanbul. Energy Build 2015;102:91–104.