

# CHALLENGES OF PASSIVE COOLING TECHNIQUES IN BUILDINGS: A CRITICAL REVIEW FOR IDENTIFYING THE RESILIENT TECHNIQUE

Article history

Received

6 October 2015

Received in revised form

11 November 2015

Accepted

15 May 2016

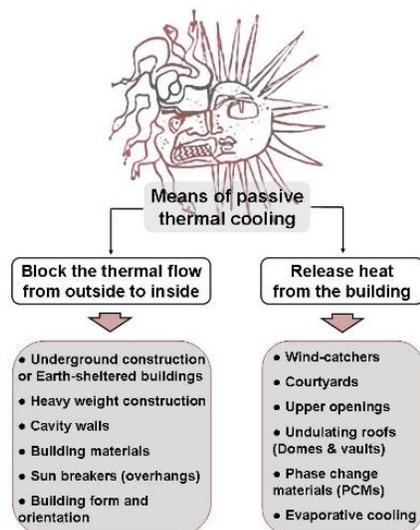
Abbas M. Hassan<sup>a</sup>, Hyowon Lee<sup>b</sup>, Segyu Oh<sup>b\*</sup>

<sup>a</sup>Department of Architecture, Faculty of Engineering, Al-Azhar University, Qena 83513, Egypt

<sup>b</sup>School of Architecture, Chonnam National University, 77 Yongbongro, Bukgu, Gwangju 500-757, Republic of Korea

\*Corresponding author  
oskar@chonnam.ac.kr

## Graphical abstract



## Abstract

Although many studies have investigated the potential of passive cooling technologies in hot and arid areas, an important question remains. Why did architects ignore the passive cooling technologies in new buildings despite their sustainability? This study is based on this pivotal question. This study aims to review and explore the impediments that undermine the use of these technologies in hot, arid areas; moreover it intends to determine the most resilient passive cooling technique which may be used as a master technique in buildings by architects. The study focuses on twelve of a proposed passive technologies. These techniques are reviewed according to their potentials and challenges. Hence, the drawbacks of each passive technique will be identified in order to recognize the most resilient passive technology. This study suggests that spatial limitations are the most salient challenges facing architects when they attempt to utilize passive cooling technologies. This study also concludes that the openings created in the upper parts of external walls is the most flexible technique that can be implemented in new and existing buildings, without any of the aforementioned impediments.

**Keywords:** Passive cooling technologies, hot arid regions, thermal comfort, Hassan Fathy, Egypt

© 2016 Penerbit UTM Press. All rights reserved

## 1.0 INTRODUCTION

Scholars and people have disassociated regarding the meaning of "the comfort". Some of them consider that it is related to physical perception such as heat and cold, light, noise, landscape and greenery, some others suggest it is far than that where it is related to socio-cultural, and psychological systems; however, there is a consensus on the strong relation between comfort and thermal behavior [1].

This study is important in terms of the prospects and applied challenges of passive cooling technologies in hot, dry regions. Many studies have focused on the potential of passive cooling technologies in hot, arid regions; however, studies that have attempted to

discuss the reasons behind the reluctance to use these technologies in new buildings, despite their sustainability, have been limited, especially in hot, arid regions.

Arid and semi-arid regions make up one-third of the world's land; the population of the desert accounts for 15% of the world's population [2]. In addition, due to the environmental changes, the modern buildings have been requiring energy for cooling more than the energy required for warming [3]. Therefore, the lack of utilization of passive cooling technologies in the buildings constructed in hot, arid zones is considered an important issue and the abandonment of these technologies by architects, despite their advantages, should be investigated. To the best of our knowledge,

this issue has not yet been covered and is thus worth exploring and discussing. Before analyzing passive cooling technologies, it is essential to evaluate the problem briefly from economic and environmental viewpoints.

Buildings are one of the major consumers of energy, as well as key producers of pollutants all over the world. The building sector consumes about 40% of the total energy used in our life [4-7]. Lombard and others [8] declared that the residential buildings consume roughly 20% to 30% from the total consumed energy especially in the developing countries. In the United States for instance; about 39% of the energy consumed is used up by buildings [9]. The building industry is responsible for half of the annual carbon dioxide emissions and 70% of the sulfur oxide emissions [4] in the country. The consumption of energy needed to cope with the local climate is considered a critical issue, especially in the hot regions of the rich gulf countries. In 1995, air-conditioning exhausted around 70% of the electrical power in the Arab Peninsula [2], and 53% in Kuwait [10].

Despite the ecological and thermal significance of passive cooling systems in buildings, architects have not utilized these technologies in new constructions. In Kuwait for example architectural design that considers climate has been neglected significantly, especially since the discovery of oil in the 1940s [10], even with the emergence of building codes that urge a rational use of energy [11]. In Mexico as well, architects have failed to take the climatic factors into consideration [12]. Sozen and Gedik [13] argued that modern Turkish buildings are dissonant with the environment and consume energy extravagantly. Alnaser and Flanagan [14] stated that 70–80% of the total energy depletion in Bahrain and the Arab gulf countries is attributed to the air-conditioned buildings, which were constructed without considering climatic in architectural design. It is worth mentioning that buildings that use air-conditioning to create thermal comfort in indoor spaces indicates a weakness in design [5]. Therefore, depending on passive cooling systems instead of air-conditioning units is considered an ideal alternative for the problems associated with energy and environment [5, 15]. Ealiwa and others [16] conducted a survey on the occupants of Ghadames in Libya; they found that the residents of old buildings that relied on traditional passive cooling elements experienced better thermal comfort than those who lived in new, air-conditioned buildings.

The question therefore posed here is: why are passive cooling technologies neglected in new buildings despite the ecological and economic benefits associated with these technologies? In order to answer this question, this study hinges on the premise that there are restrictions relevant to passive cooling technologies, which may undermine the implementation of these technologies in new buildings. Therefore, passive cooling systems should not be considered merely by their thermal performance. There are planning legislations and spatial determinants that may hinder the implementation of these technologies.

This study aims to review briefly and identify the barriers that prohibit utilizing passive cooling devices in new buildings. Furthermore, we aim to determine the passive technique that has the fewest obstacles; thereby, highlighting it as a key passive cooling technique. Thus, methodologically, this study critically reviews the performance of the passive cooling technologies and the challenges of each technique. Then, it focuses on the most resilient technique, which has the least number of barriers. This study will therefore analyze the historical approach to prove how important these technologies were for architects and builders and how they have been ignored recently.

## 2.0 METHOD AND STRUCTURE

The sustainability is a place-dependent notion [17]. Thus, the sustainable technique suitable in a particular place may not be suitable for another due to the differences among the climatic regions. This study does not aim to assess the thermal performance among the passive cooling technologies; however, its line attempts to answer this question: Why the passive cooling techniques are ignored in new buildings despite their sustainability?

The study therefore depends on the inductive approach through a critical review of twelve passive cooling techniques in order to identify the challenges; hence highlighting the resilient passive cooling technique. The study is systematically structured as following:

- Determining the criteria and challenges of passive cooling techniques. This part is presented in a table to recognize the criteria and challenges easily.
- Basing on the criteria and challenges of the selected passive cooling techniques, the barriers facing these techniques will be listed; hence we can identify the most flexible technique which can be implemented with the least possible restrictions.
- Discussing the most resilient passive technique in order to highlighting the relevance of this technique through a comparative insight between H. Fathy's schemes as an example for ecological designs and modern designs disregarding them.

## 3.0 PASSIVE COOLING TECHNOLOGIES, CRITERIA AND CHALLENGES

Preservation of historical architecture including the traditional passive cooling techniques is a moral duty not only for its artistic value but also for the permanence of regional characteristics to future generations [18].

### 3.1 Passive Cooling Technologies of Buildings

The passive cooling technologies are defined as eco-friendly techniques that contribute toward an efficient

reduction of indoor spaces temperature, either with minimal or no electrical power [19].

Traditional passive cooling techniques can contribute to designing innovative residential buildings in hot arid areas [20]. The passive cooling techniques are broadly categorized under three sections: heat prevention/reduction, thermal moderation and heat dissipation [21]. However, this classification can be simplified and divided into two types either through releasing heat from the building or by blocking the thermal flow into the building [5]. Figure 1 shows the different means of passive thermal cooling that are used in buildings. The potential of passive cooling technologies is well known.

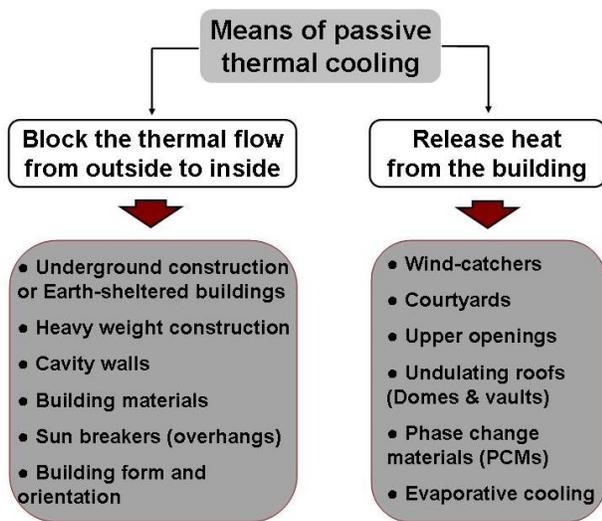


Figure 1 Passive cooling techniques in buildings

Although the passive cooling system has varied technologies, the ideal objective is thermal resistance of heat entering from the outside alongside the release of heat accumulated in indoor spaces.

This study does not intend to restate the advantages related to the passive cooling technologies; this point has already been well covered. However, the study will emphasize the limitations relevant to each technique, which prevent architects from implementing them in new buildings. For example, penetration of passive solar design in Europe is not negligible. There are some 10000 to 20000 passive solar dwellings in the European community but there are probably no more than a few hundred other buildings that incorporate such features [22].

M. Santamouris and D. Kolokotsa [23] stated that the buildings including passive cooling techniques contribute to saving 70% of energy compared to the conventional buildings. Despite prospects of passive cooling technologies in saving energy, the current implementation of such technologies in modern designs is thwarting. Thus, we would discuss the criteria and challenges of passive cooling techniques.

### 2.2 Criteria and Challenges

There are different limitations associated with passive cooling technologies in buildings. These may be a main reason for the abandonment of these technologies in the architectural design and construction of buildings. The limitations depend on the criteria that govern the quality performance of the passive thermal technologies. The challenges of each passive cooling device are proposed according to incompatibility with spatial availability (availability of sources, topography, soil characteristics, allowable built area, etc.), economic barriers (high cost of the passive technique itself, durability of the passive technique over time, maintenance cost, etc.), or planning and architectural legislations. Table 1 shows the criteria and challenges for each passive cooling method in buildings. This Table us to know the reasons behind dismissing these technologies in the modern building

Table 1 Criteria and limitations governing the eligibility of passive cooling means in hot, dry regions

Passive cooling mean	Mechanism and criteria	Limitations
1. Underground structures or Earth-sheltered buildings	<p><i>1.1 Mechanism:</i> Soil acts as an insulating material for the building. It resists the influx of heat, causing a time lag. Therefore, earth-sheltered spaces are thermally comfortable (cool in the summer and warm in the winter) [24, 25]. Earth-sheltered buildings consume 65–85% less energy than conventional buildings [26, 27]. In a study carried out in the Mediterranean Region showed that the use of cultivated soil on roofs is an effective technique for reducing the indoor energy consumption [28]. Naselli Sirocco room in Italy is a traditional earth-sheltered construction, this room decreases the indoor temperature 2 C°: 4 C° compared to outdoor temperature, it also reduces the humidity rate about 5% to 10% approving the role of soil as an approach to thermal comfort [29]. Cooling tubes are long pipes placed underground through which air is drawn. Cooling tubes are a reasonably priced</p>	<p>There are social and psychological problems due to residents feeling isolated in underground spaces. The initial cost of earth-sheltered buildings is high compared to aboveground structures. This is because of the extra reinforced structural elements resulting from the overweight of the soil [2]. The soil properties and topography may be barriers against the implementation of underground buildings. Therefore, architects may be unable to use this technique fully or be forced to implement it in a modest manner (one or two floors underground level), despite the prudent approach of the underground building technique. Underground structures need an assistant technique for natural ventilation to remedy the lack of fresh air in the underground spaces [33]. The ventilating passive technique may be courtyards or wind-catchers.</p>

		<p>natural way to passively cool the air. As the air is drawn through the pipes. It is usually used to cool and dehumidify hot outside air [30].</p> <p><i>1.2 Criteria:</i> The temperature of the earth at a depth of 2.5 to 3 m from the ground surface is significantly lower throughout the year [6]. Although, Benardos <i>et al.</i> [31] argued that the temperature at a depth of 8–10 m is annually constant due to the thermal mass reduction of soil. The underground structure needs a central courtyard and wind-catchers to induce cross ventilation [32].</p>	<p>Nevertheless, including wind catchers or courtyards in the design requires extra space.</p>
2.	Heavy weight construction	<p><i>2.1 Mechanism:</i> The heat transfer is inversely proportional to the thickness of the external walls. Time lag of heat depends on the thermal characteristics of the building material and the wall thickness [13].</p> <p><i>2.2 Criteria:</i> In order to prolong the time lag (delay the heat transmittance from outside to inside), thermal resistance, high thermal capacity, and low thermal conductivity are required characteristics of the building materials for the building envelope. Clay is a sustainable building material (it is cheap and can provide thermal comfort, in addition to being an eco-friendly material) in hot, arid zones where 30% of people still live in earthen houses [34]. Clay has a low thermal conductivity; however, resident acceptance levels of this material in modern buildings are questionable. Regardless of the thermal properties of building materials, the thick walls have to allow the penetrated heat to get out during the night in order to maintain thermal comfort [35].</p>	<p>The thick walls (0.5–0.6 m) are not preferred in limited construction areas, because these walls reduce the indoor space area. Therefore, this technique cannot be implemented everywhere especially when the land cost is expensive. Heavy weight construction is related to the bearing wall system, which has a maximum limit for height; furthermore, there is difficulty in reorganizing the indoor space because of the inflexible system of bearing wall construction. Thus, it may be unfavorable in cities. Thermally, the thick external walls delay the heat flow during the day; however, it impedes nocturnal heat release from inside the buildings to the outside. Thus, the heavy weight construction needs assistant techniques for releasing the accumulated heat; otherwise, it will contribute to creating discomfort in living spaces. The thick external walls need upper openings to empty the accumulated air in the upper space of rooms. V. Geros and others addressed buildings with different configurations in Athena to investigate the impact of ventilation on them. The nocturnal ventilation can decrease the indoor temperature by 1.8° C: 3° C; whilst it reduces just the indoor temperature by 0.8° C: 1.8° C in the light weight constructions [36].</p>
3.	Cavity walls	<p><i>3.1 Mechanism:</i> Building envelope is the interface between internal and external environment. Moreover, improving the building envelope has recorded that overall energy 10.8% [37]. The air gap between the two layers of building envelope may resist heat flow from the outer to inner layers.</p> <p><i>3.2 Criteria:</i> The gap between the two layers of the external walls should be ventilated in order to decrease heat transfer by convection [38]. The ventilation between the two layers can lead to energy savings on indoor cooling [9]. A reflective membrane, such as aluminum sheets, can be used in the gap to reflect the heat to the outer layer. Heat transfer is directly proportional to thickness of the gap. Performance of the double skin facade also depends on the materials used in each layer, the ratio between the area of wall and that of the window and split gap system of the adjacent tubes [7].</p>	<p>Danby (1973) [35] declared that the cavity walls are not thermally effective in hot, dry regions because the openings in the outer skin cannot ventilate the gap blockaded between the two layers efficiently. Thus, the heat will be rapidly transmitted to the inner layer via thermal convection. Thus, the thickness of the air gap is considered an important factor in order to resist heat flow from the outer to inner leaf of cavity wall, the gap should not be less than 200 mm to keep a well performance for cavity walls [39]. However, the total thickness of cavity walls may contradict with the area allowed for building. The gap of air could be decreased we inserted an insulation material embedded in the external leaf of the cavity walls, then the resistance of heat flux from the outside to inside can be lowered [40]. Some scholars suggested installing a reflective membrane on the inner leaf, but the reflective aluminum membrane used to reverse the heat to the outer layer will also not be efficient because of the dust that is likely to accumulate on the reflective surface.</p>
4.	Traditional building materials	<p><i>4.1 Mechanism:</i> The thermal characteristics of building materials determine the degree of heat transfer from outside</p>	<p>The thermal characteristics of building materials available in hot, dry regions are not sufficient for creating thermal comfort [32]. Therefore, their</p>

	<p>to inside. In hot, dry zones, clay and wood have low thermal conductivity, but this is not sufficient on its own. This climate needs a material with high thermal capacity.</p> <p><b>4.2 Criteria:</b> The thickness of building materials used in the peripheral walls should be increased to fulfill the thermal capacity needed in hot, dry regions. Therefore, this reintroduces the previous criteria of heavy weight construction; hence, it is necessary to remove the accumulated heat. The thermal characteristics of building materials are also so important. For example, siliceous shale is able to reduce the roof surface temperature up to 8.63o C as compared to mortar concrete [41].</p>	<p>thermal efficiency must either be improved, such as Leka brick (consists of polystyrene, clay bubble, and cement), or building techniques, such as cavity or heavy walls, must be used. In short, architects cannot solely depend on building materials to create thermal comfort in buildings. It is worth mentioning that the socio-cultural factor may dampen the desire of residents to use thermally effective materials, such as clay, due to the modest manifestation of clay that does not keep up with the social and fiscal levels of some people. Some building materials are efficient and have a good thermal characteristics such as siliceous shale which comprise of a high number of mesoporous are effectively keeping surface moisture from vapor adsorption [41], but the issue of availability is still too questionable.</p>
5. Sun breakers	<p><b>5.1 Mechanism:</b> Sun breakers installed over or around windows block solar radiation and prevent it from entering the indoor space during particular periods of the day.</p> <p><b>5.2 Criteria:</b> Dimensions, orientation, and qualities of sun breakers depended on the sun path and the location of the building. Therefore, eastern and western overhangs should be moved automatically by solar sensors to adapt to the movement of the sun; whereas, southern overhangs may be static but should encompass small openings to release heat. In the aforementioned criteria, the indoor climate can be improved if the windows are shut during the hottest period of the day [35]. Thus, the sun breakers will not be necessary from a thermal perspective.</p>	<p>The function of sun breakers is protecting the windows from intensive solar radiation; however, the glass area of windows in hot, arid zones should limited from the early design stage in order to undermine the impact of solar radiation and high luminance. Therefore, the contribution of sun breakers to thermal comfort will be a limited too. On the other hand, the implementation of overhangs will be expensive if solar sensors are incorporated into the building process. Overhangs may also reflect some of the solar radiation onto adjacent building envelopes. Horizontal overhangs prevent the rapid release of heat coming out of windows.</p>
6. Building form and orientation	<p><b>6.1 Mechanism:</b> The compact form and its orientation may reduce the heat gained through the surfaces of buildings exposed to solar radiation. Building forms providing a great deal of shadow such as undulating roofs may also contribute to proximity to thermal comfort zone.</p> <p><b>6.2 Criteria:</b> For building forms, the ratio between the exterior surface area and the enclosed volume should be minimal [42]. The orientation with the lowest heat gain in the summer is in the longitudinal direction located on the E–W axis with an aberration of 10–15 to the east [35]. Among 37 alternatives of roof forms in Cairo (Egypt), a study has been carried out to assess the optimum substitute regarding passive cooling performance. The study found that using a vault roof with high albedo coating shows a fall of 53% in discomfort hours and saves 826 kW h during the summer season compared to the base case of the conventional non-insulated flat roof [43].</p>	<p>The orientation issue is controversial. Some researchers consider that the longitudinal direction of buildings on the N-S axis is optimal, others say that NE-SW or NW-SE is ideal [44]. If the longitudinal axis of building is N-S, then the street will be in the E-W direction and the street area will suffer from thermal discomfort [45]. Building forms related to architectural legislations that specify building configurations; therefore, the ideal building form, with the best orientation that guarantees minimal heat gain, does not depend on the architect as far as dependence on the maximum exploitation of built area and height are concerned. Urban planning also intervenes in the decision on building orientation.</p>
7. Wind catchers	<p><b>7.1 Mechanism:</b> The wind catcher traps cool and fresh air from the upper air layers, moving it down and into the tower shaft where it is moistened and cooled due to association with water. The cool air then rushes towards the indoor space, providing coolness via thermal convection [46].</p>	<p>The wind-tower takes up part of the indoor space in buildings; therefore, it may not be established within the limited built-up area. Not all buildings are guaranteed to have extra space for wind-shafts or enough water to apply this method. The wind-catcher should be supplied with water sprinklers to facilitate the evaporative cooling of</p>

		<p><i>7.2 Criteria:</i> Water is a key element for the success of wind-catchers in hot, dry zones through the evaporative cooling system [47]. The internal partitions embedded in the wind shaft increase the wind velocity from 1 to 1.53 m/s [48]. The association between wind-catcher and Earth-to-Heat Exchanger produces air that is cooler than that getting from the conventional wind-catcher with wet surfaces. The wind tower dimensions (height and cross section) are not important compared to the hygrothermal pipes (length and diameter) [49,50]</p>	<p>the dry, hot air passing through the shaft. The heights of the surrounding buildings may decrease the wind velocity needed for the success of the wind-catcher. The dense urban environment may undermine the performance of wind tower [51]. The wind tower cannot work well with the slow air velocity [52]. The orientation of air inlet of the wind tower and its height are effective factors for maximizing the utilization of wind and ventilation [52].</p>
8.	Courtyards	<p><i>8.1 Mechanism:</i> The courtyard acts as storage for cool air during the night where the temperature drops to the minimal value. The cool air is then distributed into the indoor space during the hotter periods of the day [53]. Thus, small courtyards are an effective technique for cooling the high thermal mass structure through nocturnal ventilation [54, 55].</p> <p><i>8.2 Criteria:</i> Deep courtyards (ratio of height/width of 10 with minimum sky view factor) are thermally better than shallow courtyards in hot, dry areas [56]. The thermal performance of the courtyard also depends on the building materials used to build the courtyard walls [57]. A study has carried out to evaluate the thermal performance of courtyards at a primary school in Mendoza, Argentina. The study suggested that shadow portions provided by courtyard is the biggest impact on the consumed energy in classrooms [58].</p>	<p>The area required for the internal courtyard can be a major reason for the rejection of this technique, despite its ability as a thermal regulator in hot, arid areas. The cost of urban land and the privacy required in residential buildings with multi-families has forced architects to neglect the design and implementation of this technique in most new architectural schemes. The orientation of the courtyard can also positively or negatively impact the thermal performance [59, 60].</p>
9.	Upper openings in roofs or external walls	<p><i>9.1 Mechanism:</i> The accumulated hot air in the upper part of the indoor space, due to its low density, may be a source of thermal discomfort; therefore, the upper openings designed in the external walls or roofs can release the blockaded heat and enhance cross ventilation [12].</p> <p><i>9.2 Criteria:</i> The openings at the upper parts of the external walls can release heat accumulating inside the chambers; however, there may be the need for an assistant technique, such as an electrical fan, to maximize the suction process.</p>	<p>Openings in roofs may cause difficulties as dust and insects may penetrate into the indoor space. Furthermore, solar radiation is likely to rush into rooms during the mid-day period when the sun becomes semi-perpendicular. The openings of the roofs can only release accumulated heat from the top floor. However, upper openings in external walls can not only perform the same function of openings in roofs, but can also serve all the indoor space regardless of location. Thus, they are more effective than openings in the roof.</p>
10.	Undulating roofs (domes or vaults)	<p><i>10.1 Mechanism:</i> Undulating forms of roofs, such as domes and vaults, result in heterogeneous thermal pressure in the indoor space, due to differentiation between the shaded and solar-radiation-exposed parts [61].</p> <p><i>10.2 Criteria:</i> The heterogeneous thermal pressures under the skin of domes and vaults need openings to release the heat on the internal circumference of these forms. There are no limitations on the orientation of the dome, because its plan is a circle and this shape is neutrally oriented. However, the vaults should be oriented correctly to attain the greatest amount of shade and shadow; the longitudinal axis of the vault should take the direction N-S in order to enhance the ventilation through the upper</p>	<p>Construction costs for undulating forms of roofs, such as domes and vaults, are higher than those of flat roofs. The domes or vaults, which cover the upper roofs of buildings, serve the indoor space of the last floor as they cut off the potential for vertical expansion. Thus, these kinds of roofs have limited service scope and prevent the residents from using the roof for living purposes. The preferred orientation, which is supposed for vaults, cannot be infinitely reserved due to spatial and planning restrictions (existence of surrounding neighbors, number of surrounding streets (the opened facades or lot's dimensions and shapes, etc). The openings that should be created in the body of domes to release the heat are no longer acceptable today because of risks from dust, insects, and dangerous reptiles.</p>

		openings on the southern and northern sides and maximize the shade.	Undulating forms of roofs require skilled labor for their construction; thus, the costs of these roofs will be higher than flat roofs.
11. Change (PCMs)	Phase Materials	<p><i>11.1 Mechanism:</i> PCMs absorb the heat during the hot period and release it during the cold hours. Thus, these materials use latent heat to modify the indoor climate [24].</p> <p><i>11.2 Criteria:</i> The performance of PCMs depends on the daily range of temperature; these materials work efficiently when the daily range of temperature is quite big [62]. Increase of ventilation rate of indoor spaces leads to raising the heat transfer efficiency on PCMs; hence, the discomfort hours can be decreased [36].</p>	<p>PCMs materials are effective in zones that have a high daily range of temperature (the difference between the minimum and maximum temperature is quite high i.e., more than 15 °C). However, the initial cost of these materials is still high and the durability is unknown.</p> <p>The ventilation rate is really needed for growing the heat transfer between indoor air temperature and PCMs. Therefore, enhancement the cross-ventilation may support the performance of PCMs.</p>
12. Evaporative cooling		<p><i>12.1 Mechanism:</i> Evaporative cooling depends on water to convert the hot, dry air to moist, cool air. This process is effective in hot, arid zones [16, 63]. The evaporative cooling can lower the indoor air temperature by 8.5° C to 9.6° C [43]. A study has measured the cooling demands for Iberian Peninsula buildings, it is found that the evaporative cooling decrease the cooling energy about 40% [64]. In Brazil also, the evaporative cooling can reduce the indoor air temperature by 2.5° C [65].</p> <p><i>12.2 Criteria:</i> Evaporative cooling can be achieved through different means. Greeneries are an evaporative bio-technique that resist dry air and airborne dust as well [66]. Air velocity is substantial for efficiency the evaporative cooling [67].</p>	<p>Although evaporative cooling is an effective technique for decreasing air temperature in hot, dry zones [46], the drought in these regions poses a significant challenge for this technique.</p> <p>For instance, we need about 50 L/m<sup>2</sup> daily to cool the conventional roof via evaporative cooling system [68].</p>

In the next section, the passive cooling technologies presented in Table 1 will be assessed in terms of their flexibility, thermal efficiency, and adaptability as against the challenges in terms of the application of these technologies stated previously.

#### 4.0 IDENTIFYING THE GREATEST BARRIER FOR APPLICABILITY AND MOST RESILIENT TECHNIQUE

By reviewing passive cooling devices (Table 1), it became apparent that each passive technique has some limitations. Furthermore, these technologies are interconnected, which is especially true for heat blocking and release technologies (Figure 2). Therefore, these reasons may further support avoiding the use of these technologies in modern buildings, notably residential buildings. For instance, the natural ventilation systems in the residential buildings may require opening the windows for increasing airflow rates but concurrently there are some issues need to be addressed such as privacy, noise of streets and protection against thefts [79]. However, some of these technologies have a few barriers to achieving thermal comfort and can be associated with other

technologies. Table 1 introduces the prospects of upper openings. Upper openings designed for roofs have some challenges; For example, there is a lack of thermal feasibility as these openings serve only the indoor space of the final floor. However, the upper openings in the building envelope have no conflicts with any barriers, in addition to their flexible incorporation with different passive cooling technologies (Figure 2).

Figure 2 derived from Table 1, shows the connection between the passive technologies for blocking and releasing heat from indoor spaces. Only one of the cooling passive techniques cannot provide thermal comfort zone without association with another technique. For example, roof ponds cannot lower the energy demands without collaboration with further passive devices [70]. Also, a study carried in Delhi, suggests that evaporative cooling alongside the cooking ventilation are silent partner for succeeding other passive cooling technologies such as insulation the external walls and roofs [71]. Statistically, as shown from Figure 2, heavy weight construction that has a

Thick building envelope can associate with three heat release technologies (wind-catchers, courtyards, and upper openings in the walls or roofs) to achieve thermal comfort zones. Building forms and orientation are also connected with three passive technologies. On

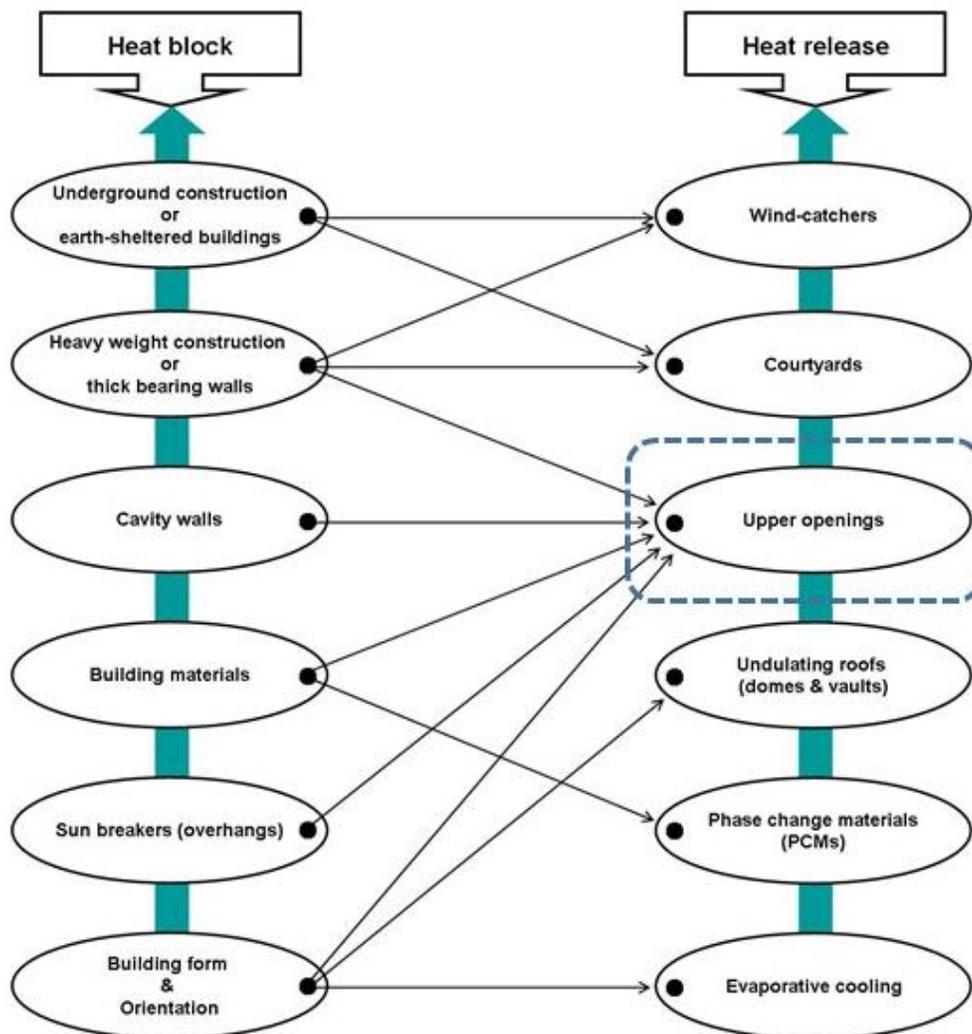
the other hand, the upper openings, which are designed to be placed in external walls, can enhance the thermal performance of five passive technologies. Thus, this technique appears to be the most resilient among the passive cooling technologies and can economically adapt with spatial and temporal factors.

The openings in the upper part of the external walls may need a small electric fan to help draw the hot air accumulated in the upper part of the indoor space and maximize the ventilation process. In England for example, the combination between electric fans and natural ventilation enhances the thermal comfort [72]. The outer walls of the buildings need to be insulated by a material such as polystyrene in order to be lightweight and thin; then, keep up with the skeletal structures and avoid the problems of cavity walls and the area consumed by thick bearing walls.

The limitations that undermine the role of passive cooling systems in modern architecture are numerous. The limitations that may control these technologies can

be categorized into four types, as shown in Table 2. Economic limitations measure the affordability criteria of establishing these technologies through the use of local building materials. The second restriction is legislative limitations that are relevant to architectural design and planning.

These restrictions assess the applicability of each passive cooling technique against potential architectural regulations, such as building codes or local housing laws. The third one is spatial restrictions that are related to the possibility of implementing passive technologies in limited building spaces (building lot) and in different parts of the building. The fourth limitation is relevant to the socio-cultural dimensions, which evaluate the acceptability of the passive technique according to socio-cultural factors. These determine the ease of establishing the passive cooling technique through resident contribution to the building process; thus, it can be another indicator for socio-cultural acceptance.



**Figure 2** Connection between passive cooling techniques and the complementary frame of a successful technique. The technique of upper openings seems adaptable with several other passive techniques. Thus, this indicates that the upper openings technique is more flexible than the others are

The most resilient passive cooling technique, which has almost no conflicts with any of the restrictions, is the upper openings in external walls that are used to release the heat accumulated in the indoor space, as shown as Table 2. The upper vents in the building envelope enhance the indoor ventilation that is an

inevitable copartner with any cooling passive technique [73]. The spatial restrictions seem to be the greatest barrier against the implementation of the passive cooling technologies (Table 2). This kind of limitation scored 11 points against the applicability of these technologies.

**Table 2** Limitations relevant to passive cooling techniques that may confront architects when they try to implement them ([O] refers to satisfying the limitation or having no conflicts with it; [X] indicates conflict with the limitation)

Passive cooling techniques	Limitations						
	Economic	Legislative		Spatial		Human and social	
	Affordability through use of available local building materials	Compliance with architectural design codes	Adaptability with planning determinants	Suitability with limited built area	Applicability wherever architects need	Need for special technical individual skills	Keeping up with socio-cultural factors
1. Underground structures	O	X	X	O	X	X	X
2. Heavy weight construction	O	O	O	X	X	O	X
3. Cavity walls	X	O	O	X	X	X	O
4. Local building materials	O	O	O	X	X	O	X
5. Sun breakers	X	O	O	O	X	X	O
6. Building form and orientation	O	X	X	X	X	X	X
7. Wind catchers	X	O	X	X	X	X	O
8. Courtyards	X	X	X	X	X	X	O
9. Upper openings external walls	O	O	O	O	O	O	O
10. Undulating roofs (domes or vaults)	O	O	X	O	X	X	X
11. Phase Change Materials (PCMs)	X	O	O	O	X	O	O
12. Evaporative cooling	O	O	O	X	X	X	O
Indicator of limitations	5	3	5	7	11	8	5

## 5.0 DISCUSSION ON THE RELEVANCE OF UPPER OPENINGS IN PERIPHERAL WALLS

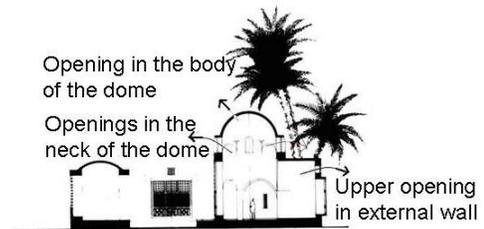
People spend around 90% of their life inside buildings [74]; therefore, buildings should provide a healthy environment and be energy sufficient. According to the second law of thermodynamics<sup>1</sup>, passive cooling technologies must be vigorously used in hot and dry regions. Energy efficiency may be achieved through building legislations, use of appropriate building materials and adopting of eco-friendly technologies; however, the efficiency would be maximized if the architectural design depends on the concept of energy efficiency early [75]. Heat release from indoor spaces contributes to enhancing thermal comfort and removing internal air pollution with fresh air ventilation [76, 77]. In this section, the thermal performance of upper openings, as well as the reasons behind the failure of implementing such techniques in modern buildings are discussed.

### 5.1 Eligibility for Upper Openings

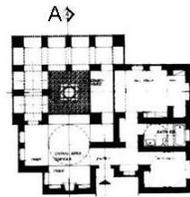
There is no doubt that Hassan Fathy is one of the pioneers of eco-architecture and affordable architecture [78] especially in the Middle East that has a predominantly hot dry climate. Fathy built his concepts on real and intensive studies of ancient passive technologies derived from the Fatimid, Mamluk, and Ottoman houses and palaces. He was considered one of the few architects who understood the meaning for sustainability in the beginning of the 20<sup>th</sup> century. Fathy derived some cooling passive concepts from the ancient architectural legacy. For example, methods for ventilating and releasing accumulated heat are considered distinguished technologies. They were implemented in several ways, such as openings in the body and neck of domes, windows in the upper part of the external walls, courtyards, and wind-catchers. This part will focus on the technique of upper openings by Fathy, which is currently missing in modern buildings.

For example, would using a dome reduce solar gain within roofs? This, supposedly, was the question posed by a study applied on a digital simulation model. Consequently, this study evaluates solar gain, due to the impact of direct and diffused radiation on both dome and flat roofs. The results show that the solar gain of domes exceeded that of the flat roof counterparts by 19% in the summer and 43% in the winter in Cairo (30° North) [79]. In fact, this result contradicts the thermal perception of indoor spaces covered by domes; hence, it opposes Fathy's fascination with domes and vaults. Domes are a complicated form. From the previous results, it is clear that the numerical simulation, though acceptable, neglects some parameters, which may affect the thermal performance of domes. Fathy had created some openings in the body of the dome as well as the neck. The openings helped to

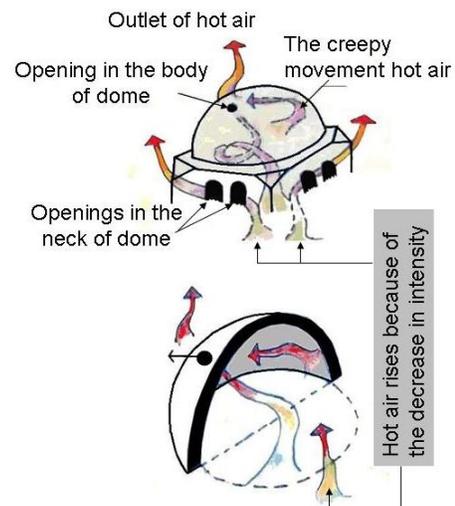
release the accumulated heat, which was under the envelope of the dome. Therefore, the cool air that occupies the bottom part of the indoor space will move up to replace the heat that has escaped through the openings. Figure 3 shows the openings that are designed by Fathy in the body of dome and upper part of the peripheral wall, in addition to the continuous movement of the hot air around the inner surface of that contributes to decrease the heat flow through the envelope of dome [78, 80]. The Prince Sadr-eldin Aga Khan House is a model for many designs by Fathy that included the same techniques aiming to create thermal comfort micro-zones.



Section A



Prince Sadr-eldin Aga Khan House, Aswan, South Egypt



A section in dome shows the circulation of hot air

**Figure 3** Schematic of Fathy design with openings at the neck of the dome and on the upper part of the external walls in Prince Sadr-eldin Aga Khan House in Aswan, South Egypt; despite the existence of a window on the external wall, the upper opening also is important for releasing heat

<sup>1</sup> "The Second Law of Thermodynamics decrees it impossible to have any organism or machine operating at 100% efficiency. Hence it is

impossible to operate any system, whether it is engaged in production or pollution control, without some waste of energy or materials".

## 5.2 Neglecting Upper Openings in New Buildings

Fathy grasped the thermal dynamic concepts and studied the behavior of heat flow; more so than anyone else study, during his lifetime. The opening at the top provides ventilation and allow hot air collected at top to escape from indoor spaces. Arrangements may be made to draw air from the coolest part of the structure as replacement, to set up a continuous circulation and cool the living spaces [81]. On the other hand, Middle Eastern architects who came after him did not utilize these technologies to the same extent as shown in Figure 4(a,b). They also did not realize that the social view of residents has changed. For instance, the openings designed by Fathy in the body of the dome to release the heat did not cause a problem for the dwellers in the past, even if dust or insects penetrated the indoor chambers through the openings. Nowadays,

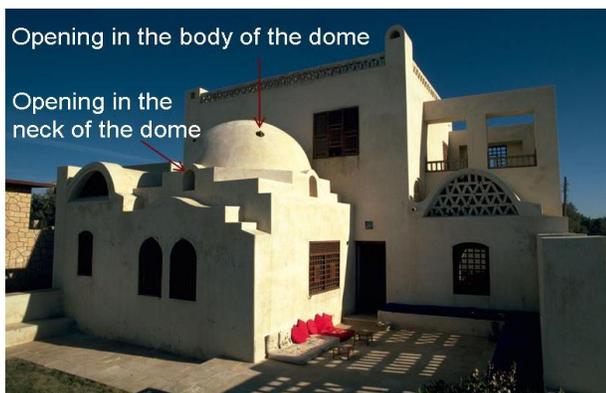
the social view has changed. Therefore, what was accepted during Fathy's time is not necessarily acceptable today. Contemporary architects have not tried to solve the discrepancy between social determinants and the use of passive ancient techniques. Residents due to an old perception have disliked some passive cooling techniques. Therefore, validating of users' perception through highlighting the pros of passive techniques and implementing it modernly [82]. Eventually, the in depth understanding of air circulation and use of passive technologies will comply with the requirements of contemporary living standards as shown in Figure 4-c where the openings in the body of the dome were provided with cover to allow residents to shut and open whenever they need. Grasping the socio-cultural dimension helps architects to use the passive cooling technologies efficiently.



a) Affordable houses, 6th of October City, Cairo [83]. The upper openings were neglected in the body and neck of the domes and in the external walls as well



b) Orascom Housing scheme [83], 6th of October City, Cairo. The upper openings are missed in the external walls and vaults



c) Halawa house, Agami, Egypt [84]. Architect: Abd El-Wahed El-Wakel (H. Fathy's student), Aga Khan award, 1980. The architect designed openings in the body and neck of the dome. It is worth mentioning that the openings located in the body of the dome have a cover to be closed when residents need



d) Rest house, Aswan, Egypt. Architect: Hassan Fathy. The upper openings are existed clearly in the external walls, vaults and even in the dome

**Figure 4** The upper openings were missed in the modern residential schemes as shown on the left, this technique was emphasized in the architectural design that takes climate into consideration as shown on the right

## 6.0 CONCLUSION

Undoubtedly, the internal thermal comfort of buildings cannot be achieved using one passive cooling mean alone. Thus, association between two or more technologies is inevitable. This study identified the greatest barrier against the implementation of passive cooling technologies that is spatial restriction; applying passive cooling technologies wherever they are required in buildings. Therefore, overcoming the reluctant to introduce passive cooling technologies into new schemes is a big challenge.

The leading passive cooling technique is the use of upper openings created in peripheral walls. It can be implemented in the external walls of all indoor spaces and is associated with different passive technologies, as shown in Figure 2. Therefore, architects should recruit this technique in new buildings in order to create thermal comfort zones. This technique can also be created easily in existing buildings ex post facto because it does not have economic, spatial, socio-cultural, or legislative impediments.

It is worth mentioning that the upper openings may need to be fitted with electrical fans to maximize heat suction from the indoor spaces. The upper openings can be used without the need for further insulation material in the bearing wall system; however, if architects need to recruit this technique in the skeletal building structures, the external walls would need to be insulated by thermal materials such as polystyrene, in order to decrease the thickness of these walls and cope with the spatial limitations.

## Acknowledgement

This research was supported by a grant (15CTAP-C098327-01) from Infrastructure and Transportation Technology Promotion Research Program funded by Ministry of Land, Infrastructure and Transport of Korean government.

## References

- [1] Houda, M. Djamel, A. Fayçal, L. 2015. An Assessment Of Thermal Comfort And Users' "Perceptions" In Office Buildings-Case Of Arid Areas With Hot And Dry Climate. *Energy Procedia*. 74: 243-250.
- [2] Al-temeemi, A. A., Harris, D. J. 2004. A Guideline For Assessing The Sustainability Of Earth-Sheltered Mass-Housing In Hot-Arid Climates. *Energy and Buildings*. 36: 251-260.
- [3] IEA. 2007. Renewables For Heating And Cooling. International Energy Agency. Available online at [www.iea.org](http://www.iea.org). 25.
- [4] Aldossary, N. A. Rezgui, Y. Kwan, A. 2014. Domestic Energy Consumption Patterns In A Hot And Arid Climate: A Multiple-Case Study Analysis. *Renewable Energy*. 62: 369-378.
- [5] Samuel, D. G. L. Nagendra, S. M. S. Maiya, M. P. 2013. Passive Alternatives To Mechanical Air Conditioning Of Building: A Review. *Building And Environment*. 66: 54-64.
- [6] Santamouris, M. Kolokotsa, D. 2013. Passive Cooling Dissipation Techniques For Buildings And Other Structures: The State Of The Art. *Energy and Buildings*. 57: 74-94.
- [7] Hamza, N. 2008. Double Versus Single Skin Facades In Hot Arid Areas. *Energy and Buildings*. 40: 240-248.
- [8] Lombard, L. P., Ortiz, C., Pout, C. 2008. A Review On Buildings Energy Consumption Information. *Energy and Buildings*. 40: 394-398.
- [9] Sadineni, S. B. Madala, S. Boehm, R. F. 2011. Passive Building Energy Savings: A Review Of Building Envelope Components. *Renewable and Sustainable Energy Reviews*. 15: 3617-3631.
- [10] Al-Temeemi, A. 1995. Climatic Design Techniques For Reducing Cooling Energy Consumption In Kuwait Houses. *Energy and Buildings*. 23: 41-48.
- [11] Roodgar, M. Mahmoudi, M.M. Ebrahimi, P. Molaei, D. 2011. Sustainability, Architectural Topology And Green Building Evaluations Of Kashan-Iran As A Hot-Arid Region. *Procedia Engineering*. 21: 811-819.
- [12] Porta-Gandara, M. A. Rubio, E. Fernandez, J. L. Munoz, V. G. 2002. Effect Of Passive Techniques On Interior Temperature In Small Houses In The Dry, Hot Climate Of Northwestern Mexico. *Renewable Energy*. 26: 21-135.
- [13] Sozen, M. S. Gedik, G. Z. 2007. Evaluation Of Traditional Architecture In Terms Of The Building Physics: Old Diyarbakir Houses. *Building and Environment*. 42: 1810-1816.
- [14] Alnaser, N. W. Flanagan, R. 2007. The Need Of Sustainable Buildings Construction In The Kingdom Of Bahrain. *Building and Environment*. 42: 495-506.
- [15] Kharrufa, S. N. Adil, Y. 2012. *Upgrading The Building Envelope To Reduce Cooling Loads*. *Energy and Buildings*. 55: 389-396.
- [16] Ealiwa, M. A. Taki, A. H. Howarth, A. T. Seden, M. R. 2001. An Investigation Into Thermal Comfort In The Summer Season Of Ghadames, Libya. *Building and Environment*. 36: 231-237.
- [17] Hassan, A. M. Lee, H. 2015. The Paradox Of The Sustainable City: Definitions And Examples. *Environ Dev Sustain*. 17: 1267-1285.
- [18] Hassan, A. M. Lee, H. Yoo, U. 2014. Evaluation Of The Contemporary Urban Design Through The Classic Urban Theories: Cairo And Gwangju Downtown As A Case Study. *HBRC Journal*. 10(3): 327-338.
- [19] Waqas, A. Din, Z.U. 2013. Phase Change Material (PCM) Storage For Free Cooling Of Buildings – A Review. *Renewable and Sustainable Energy Reviews*. 18: 607-625.
- [20] Foruzanmehr, A. Nicol, F. 2008. Towards New Approaches For Integrating Vernacular Passive-Cooling Systems Into Modern Buildings In Warm-Dry Climates Of Iran. Air Conditioning and the Low Carbon Cooling Challenge Conference, 2008. Cumberland Lodge, Windsor, UK, 27-29 July 2008. <http://nceub.org.uk>.
- [21] Geetha, N. B. Velraj, R. 2012. Passive Cooling Methods For Energy Efficient Buildings With And Without Thermal Energy Storage—A Review. *Energy Education Science and Technology Part A: Energy Science and Research*. 29(2): 913-946
- [22] European Commission. 1994. The European Renewable Energy Study. Altener Programme. Rectorate General Energy.
- [23] Santamouris, M. Kolokotsa, D. 2013. Passive Cooling Dissipation Techniques For Buildings And Other Structures: The State Of The Art. *Energy and Buildings*. 57: 74-94.
- [24] Givoni, B. 2007. Cooling Soil As A Cooling Source For Buildings. *Solar Energy*. 81: 316-328.
- [25] Dronkelaar, C.V. Cóstola, D. Mangkuto, R. A. Hensen, J. L. M. 2013. Heating And Cooling Energy Demand In Underground Buildings: Potential For Saving In Various Climates And Functions. *Energy And Buildings*. 71: 129-136.
- [26] Durmisevic, S. 1999. *The Future of The Underground Space, Cities*. 16(4): 233-245.
- [27] Khair-El-Din, A. 1990. Energy Conservation And Its Implication For Architectural Design And Town Planning In The Hot-Arid Areas Of Saudi Arabia And The Gulf States. *Solar & Wind Technology*. 7(2-3): 131-138.

- [28] Zinzi, M. Agnoli, S. 2012. Cool And Green Roofs. An Energy And Comfort Comparison Between Passive Cooling And Mitigation Urban Heat Island Techniques For Residential Buildings In The Mediterranean Region. *Energy and Buildings*. 55: 66-76.
- [29] Saëli, M. Saëli, E. 2015. Analytical Studies Of The Sirocco Room Of Villa Naselli-Amberli: A XVI Century Passive Cooling Structure In Palermo (Sicily). *Journal of Cultural Heritage*. 16: 344-351.
- [30] Zaki, A. K. Amjad, A. Almssad, A. 2007. Cooling By Underground Earth Tubes. *2nd PALENC Conference and 28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century, 2007 Crete island, Greece, September 2007*. 517-520.
- [31] Benardos, A. Athanasiadis, I. Katsoulakos, N. 2014. Modern Earth Sheltered Constructions: A Paradigm Of Green Engineering. *Tunnelling and Underground Space Technology*. 41: 46-52.
- [32] Hassan, A. M. Lee, H. 2014. A Theoretical Approach To The Design Of Sustainable Dwellings In Hot Dry Zones: A Toshka Case Study. *Tunnelling and Underground Space Technology*. 40: 251-262.
- [33] Da-yong, X. Cun-feng, Z. Ke, Y. Xu-hai, P. 2014. Feasibility Analysis On Natural Ventilation Scheme For Large Underground Spaces Based On The Top Cover Design. *Tunnelling and Underground Space Technology*. 44: 23-32.
- [34] Sheweka S. 2011. Using Mud Bricks As A Temporary Solution For Gaza Reconstruction. *Energy Procedia*. 6: 236-240.
- [35] Danby, M. 1973. The Design of Building in Hot-dry Climates and the Internal Environment. *Building International*. 6(1): 67.
- [36] Jiao, F. Xu, P. 2015. Simulation And Feasibility Analysis Of PCM Based Passive Cooling Technique In Residential House. 9th International Symposium On Heating, Ventilation and Air Conditioning (ISHVAC) and the 3rd International Conference on Building Energy and Environment (COBEE). *Procedia Engineering*. 121: 1969-1976.
- [37] Al-Saffar, M. 2015. Passive Cooling Strategies in Greening Existing Residential Building in Hot Dry Climate: Case Study in Bahrain. *Journal of Environmental Science and Engineering A*. 4: 233-240.
- [38] Hashemi, N. Fayaz, R. Sarshar, M. 2010. Thermal Behaviour Of A Ventilated Double Skin Façade In Hot Arid Climate. *Energy and Buildings*. 42: 1823-1832.
- [39] Poirazis, H. 2004. Double Skin Façades for Office Buildings. Literature Review. Report EBD-R-04/3. Division of Energy and Building Design. Department of Construction and Architecture. Lund Institute of Technology, Sweden
- [40] Ridouane, E. Bianchi, M. 2011. Thermal Performance of Uninsulated and Partially Filled Wall Cavities. *ASHRAE Annual Conference, 2011 Montreal, Quebec. 25-29 June*.
- [41] Chan, H., Riffat S. B. Zhu, J. 2010. Review Of Passive Solar Heating And Cooling Technologies. *Renewable and Sustainable Energy Reviews*. 14: 781-789.
- [42] Markus, T. A. Morris, E. N. 1980. *Building, Climate and Energy*. London: Spottiswoode Ballantyne Ltd. 373-374.
- [43] Dabaieh, M. Wanas, O. Hegazy, M. A. Johansson, E. 2015. Reducing Cooling Demands In A Hot Dry Climate: A Simulation Study For Non-Insulated Passive Cool Roof Thermal Performance In Residential Buildings. *Energy and Buildings*. 89: 142-152.
- [44] Ali-Toudert, F. Mayer, H. 2006. Numerical Study On The Effects Of Aspect Ratio And Orientation Of An Urban Street Canyon On Outdoor Thermal Comfort In Hot And Dry Climate. *Building and Environment*. 41: 94-108.
- [45] Kruger, E. Pearlmutter, D. Rasia, F. 2010. Evaluating The Impact Of Canyon Geometry And Orientation On Cooling Loads In A High-Mass Building In A Hot Dry Environment. *Applied Energy*. 87: 2068-2078.
- [46] Bouchahm, Y. Bourbia, F. Belhamri, A. 2011. Performance Analysis And Improvement Of The Use Of Wind Tower In Hot Dry Climate. *Renewable Energy*. 36: 898-906.
- [47] Kalantar, V. 2009. Numerical Simulation Of Cooling Performance Of Wind Tower (Baud-Geer) In Hot And Arid Region. *Renewable Energy*. 34: 246-254.
- [48] Hosseinnia, S. M. Saffari, H. Abdous, M. A. 2013. Effects Of Different Internal Designs Of Traditional Wind Towers On Their Thermal Behavior. *Energy and Buildings*. 62: 51-58.
- [49] Chávez, J. R. G. 2014. Application of Combined Passive Cooling and Passive Heating Techniques to Achieve Thermal Comfort in a Hot Dry Climate. *Energy Procedia*. 57: 1669-1676.
- [50] Benhammou, M. Draoui, B. Zerrouki, M. Marif, Y. 2015. Performance Analysis Of An Earth-To-Air Heat Exchanger Assisted By A Wind Tower For Passive Cooling Of Buildings In Arid And Hot Climate. *Energy Conversion and Management*. 91: 1-11.
- [51] Santamouris, M. Pavlou, K. Synnefa, A. Niachou, K. Kolokotsa, D. 2007. Recent Progress On Passive Cooling Techniques Advanced Technological Developments To Improve Survivability Levels In Low-Income Households. *Energy and Buildings*. 39: 859-866.
- [52] Bahadori, M. N. 1994. Variability Of Wind Tower In Achieving Summer Comfort In The Hot Arid Regions Of The Middle East. *Renewable Energy*. 5(2): 879-892.
- [53] Soutullo, S. Olmedo R. Sanchez, M. N. Heras, M. R. 2011. Thermal Conditioning For Urban Outdoor Spaces Through The Use Of Evaporative Wind Towers. *Building and Environment*. 46: 2520-2528.
- [54] Kubota, T. Toe, D. H. C. 2015. Application Of Passive Cooling Techniques In Vernacular Houses To Modern Urban Houses: A Case Study Of Malaysia. *Procedia – Social and Behaviour Science*. 179: 29-39.
- [55] Toe, D. H. C., Kubota, T. 2015. Comparative Assessment Of Vernacular Passive Cooling Techniques For Improving Indoor Thermal Comfort Of Modern Terraced Houses In Hot-Humid Climate Of Malaysia. *Solar Energy*. 114: 229-258.
- [56] Johansson, E. 2006. Influence Of Urban Geometry On Outdoor Thermal Comfort In A Hot Dry Climate: A Study In Fez, Morocco. *Building and Environment*. 41: 1326-1338.
- [57] Aldawoud A. 2008. Thermal Performance Of Courtyard Buildings. *Energy and Buildings*. 40: 906-910.
- [58] Cantón, M. A., Ganem, C., Barea, G., Llano, J. F. 2014. Courtyards As A Passive Strategy In Semi Dry Areas. Assessment Of Summer Energy And Thermal Conditions In A Refurbished School Building. *Renewable Energy*. 69: 437-446.
- [59] Bourbia, F. Awbi, H. B. 2004. Building Cluster And Shading In Urban Canyon For Hot Dry Climates – Part 2: Shading Simulations. *Renewable Energy*. 29: 291-301.
- [60] Meir, I. A. 1995. Pearlmutter D, Etzion Y. On The Microclimatic Behavior Of Two Semi-Enclosed Attached Courtyards In A Hot Dry Region. *Building and Environment*. 30(4): 563-572.
- [61] Rudofsky B. 1990. *Architecture Without Architect: A Short Introduction To Non-Pedigreed Architecture* (Third Printing, New York :university of New Mexico. 146-148.
- [62] Thambidurai, M. Panchabikesan, K. N. K. M., Ramalingam, V. 2015. Review On Phase Change Material Based Free Cooling Of Buildings—The Way Toward Sustainability. *Energy Storage*. 4: 74-88.
- [63] Nahar, N. M. Sharma, P. Purohit, M. M. 1999. Studies On Solar Passive Cooling Techniques For Arid Areas. *Energy Conversion & Management*. 40: 89-95.
- [64] Campaniço, H. Soares, P. M. M. Hollmuller, P. Cardoso, R. M. 2016. Climatic Cooling Potential And Building Cooling Demand Savings: High Resolution Spatiotemporal Analysis Of Direct Ventilation And Evaporative Cooling For The Iberian Peninsula. *Renewable Energy*. 85: 766-776.
- [65] Cruz, E. G. Krüger, E. 2015. Evaluating The Potential Of An Indirect Evaporative Passive Cooling System For Brazilian Dwellings. *Building and Environment*. 87: 265-273.
- [66] Tsoar, E. E. H. 1997. An Experimental Evaluation Of Strategies For Reducing Airborne Dust In Desert Cities. *Building and Environment*. 32(3): 225-236.
- [67] Guan, L. Bennett, M. Bell, J. 2015. Evaluating The Potential Use Of Direct Evaporative Cooling In Australia. *Energy and Buildings*. 108: 185-194.
- [68] Nahar, N. M. Sharma P. Purohit, M. M. 2003. Performance Of Different Passive Techniques For Cooling Of Buildings In Arid Regions. *Building and Environment*. 38(1): 109-116.

- [69] IEA. 1995. Annex 28 - Low Energy Cooling: Review of Low Energy Technologies. Report for Energy Conservation in Buildings and Community Systems Programme, Natural Resources Canada I CANMET: Canada.
- [70] Sharifi, A. Yamagata, Y. 2015. Roof Ponds As Passive Heating And Cooling Systems: A Systematic Review. *Applied Energy*. 160: 336-357.
- [71] Nix, E. Das, P. Jain, N. Davies, M. 2015. Strategies For Reducing Poor Indoor Air Quality And Adverse Temperature Exposure In Delhi's Households: A Multi-Objective Assessment. *Building Serv. Eng. Res. Technol.* 36(2): 230-246.
- [72] Gupta, R., Gregg, M., Williams, K. 2015. Cooling The UK Housing Stock Post-2050s. *Building Serv. Eng. Res. Technol.* 36(2): 196-220.
- [73] Dabaieh, M., Wanas, O., Hegazy, M. A., Johansson, E. 2015. Reducing Cooling Demands In A Hot Dry Climate: A Simulation Study For Non-Insulated Passive Cool Roof Thermal Performance Inresidential Buildings. *Energy and Buildings*. 89: 142-152.
- [74] Abounnaga, M. 2013. Sustainable Building For A Green And An Efficient Built Environment: New And Existing Case Studies In Dubai. *Sustainability, Energy and Architecture*. 131-170.
- [75] Jayswal, M. 2012. To Examine The Energy Conservation Potential Of Passive & Hybrid Downdraught Evaporative Cooling: A Study For Commercial Building Sector In Hot And Dry Climate Of Ahmedabad. *Energy Procedia*. 30: 1131-1142.
- [76] Al-Sallal, K. A., Al-Rais, L. 2011. Outdoor Airflow Analysis And Potential For Passive Cooling In The Traditional Urban Context Of Dubai. *Renewable Energy*. 36: 2494-2501.
- [77] Milner, J. Hamilton, I. Shrubsole, C. Das, P. Chalabi, Z. Davies, M. Wilkinson, P. 2015. What Should The Ventilation Objectives Be For Retrofit Energy Efficiency Interventions Of Dwellings? *Building Serv. Eng. Res. Technol.* 36(2): 221-229.
- [78] Steele J. 1997. An Architecture For People: The Complete Works Of Hassan Fathy. New York: Whitney Library of Design. 85-93.
- [79] Fekry, A.A. El-zafarany, A. 2002. Quantitative Evaluation of Shading Patterns of Domes And Its Impact on Roof Solar Gain. Symposium on Urban Development in Arid Regions and Associated Problems, Riyadh. [online] Available: <http://ipac.kacst.edu.sa/edoc/1423/139582.1-423300638.pdf>; 2013 [accessed 17/01/2013].
- [80] Serageldin, I. 2007. Hassan Fathy. Egypt: Alexandria: The bibliotheca. Egypt.
- [81] Kamal, M. A. 2012. An Overview of Passive Cooling Techniques in Buildings: Design Concepts and Architectural Interventions. *Acta Technica Napocensis: Civil Engineering & Architecture*. 55(1): 84-97.
- [82] Foruzanmehr, A. 2015. People's Perception Of The Loggia: A Vernacular Passive Cooling System In Iranian Architecture. *Sustainable Cities and Society*. 19: 61-67.
- [83] Smith, D. A. 2015. Affordable housing in Egypt. Report to Affordable Housing Institute Developing Affordable Housing Ecosystems Worldwide. Available online at: <<http://affordablehousinginstitute.org/blogs/us/2012/06/affordable-housing-in-egypt.html>>, access date: March, 18th, 2015.
- [84] Akdn. 2015. Aga Khan Award for Architecture. Available online at: <<http://www.akdn.org/architecture/project.asp?id=60>>, access date: March, 18th, 2015.