3 Passive cooling techniques

3.1 Vernacular buildings

Vernacular buildings are local buildings that have evolved overtime in one location to suit the local climate, culture and economy (Meir & Roaf, 2003). The construction of vernacular buildings uses locally available resources to address local needs. These kinds of structures evolve over time to reflect the environmental, cultural and historical context in which they exist (Coch, 1998). The building knowledge of this type of architecture is always handed down traditions and is thus more based on the knowledge achieved by trial and error and in this way handed down through the generations (Singh et al., 2009). Vernacular buildings are most often residential buildings. People have traditional lifestyles in vernacular buildings in virtually every climate in the world, from the Arctic circle to the tropics, in temperatures from below zero to over 40°C, and historically without the benefit of gas or electrically driven mechanized heating and cooling systems (Meir & Roaf, 2003).

After the emergence of modernist architecture, aided by the industrial revolution, vernacular buildings are seen to be in a state of decline and are frequently looked down upon, abandoned, neglected or actively demolished. Associated, by many at least, with an out-dated past and poverty, they are steadily replaced by architectural models that favour more modern, inter-national technologies, materials and forms (Oliver, 1997). It is assumed, as in international standards such as CENASO 7730 or ASHRAE 55, that people suffer less discomfort in very closely controlled conditions, then such vernacular buildings, along with modern passive buildings, cannot provide their occupants with 'comfortable' indoor climates (Santamouris, 2007). But nowadays, by the more and more important issues of energy consumption in building construction sectors, the continuity of the vernacular traditions is emphasized in academic research and building practice because of its climate-response, passive

TOC

model and low-energy consumption. The principles that were used in traditional buildings can very well be implemented in modern buildings so as to produce “energy saving” buildings. If these principles are sensibly adopted in modern buildings, it should be possible to build sustainable buildings for the future (Shanthi Priya, Sundarraja, Radhakrishnan, & Vijayalakshmi, 2012). We can learn a lesson from the approach of the builders who acknowledged the interdependence of human beings, buildings and physical environment (Coch, 1998). A “new vernacular” can be developed, harnessing the types of low-tech solutions that are familiar to most of us from the vernacular, together with modern passive and active renewable energy technologies and strategies to reflect the new cultural, climatic and economic realities of the 21st century (Meir & Roaf, 2003).

Vernacular buildings have to adapt to the environment through low-tech methods. Changing building form and material is the most important technique to adapt to the environment to obtain the best comfortable living space, in another words, the environment deeply influenced building form design and material use. Fathy (1986) described the climate effect on building form generation in vernacular building as: “For example, the proportion of window to wall area becomes less as one moves toward the equator. In warm areas, people shun the glare and heat of the sun, as demonstrated by the decreasing size of the windows. In the subtropical and tropical zones, more distinctive changes in architectural form occur to meet the problems caused by excessive heat. In Egypt, Iraq, India, and Pakijstan, deep loggias, projecting balconies, and overhangs casting long shadows on the walls of buildings are found. Wooden or marble lattices fill large openings to subdue the glare of the sun while permitting the breeze to pass through. Such arrangements characterize the architecture of hot zones, and evoke comfort as well as aesthetic satisfaction with the visible endeavour of man to protect himself against the excessive heat”.

In recent years, a significant amount of research has looked specifically at environmental performance issues of vernacular architecture, including its thermal properties, energy consumption and resources (Foruzanmehr & Vellinga, 2011). Both qualitative and quantitative such as field measurements, field surveys, statistical methods, comparative study and computer simulation methods are used in the investigation of the performance of vernacular buildings. Professor Paul Oliver of Oxford University compiled the book “Dwellings: Encyclopedia of Vernacular Architecture” and published in 1997 with 4000 pages collection of research by over 750 authors from 80 countries. With two volumes categorized by climate and the ‘‘vernacular responses’’ of a plethora of cultures and another volume focused on materials, resources and production, it is the world’s foremost source for research in the area (Zhai & Previtali, 2010). Zhai and Previtali (2010) introduced an approach to categorizing distinct vernacular regions and evaluate energy performance of ancient vernacular homes as well as identify optimal constructions using vernacular building techniques. Chandel, Sharma, and Marwah (2016) reviewed the vernacular architecture features affecting indoor thermal comfort conditions and energy efficiency for adaptation in modern architecture to suit present day lifestyles. Singh et al. (2009) carried out a qualitative analysis on the vernacular buildings in north-east India. And Shanthi Priya et al. (2012) have conducted the qualitative and quantitative analysis to investigate the indoor environmental condition of a vernacular residential building in coastal region of Nagapatinam, India. Cardinale, Rospi, and Stefanizzi (2013) performed one experimental research on two types of vernacular buildings which lie in Southern Italy. Nguyen, Tran, Tran, and Reiter (2011) carried out an investigation on climate responsive design strategies of vernacular housing in Vietnam by a new research methodology which is adapted to the natural and social context of Vietnam. Ng and Lin (2012) analysed the microclimate of two Minangkabau vernacular houses in villages of Balimbing of Bukittinggi, Sumatra, Indonesia. Ali-Toudert, Djenane, Bensalem, and Mayer (2005) addressed the issue of outdoor thermal comfort in a hot and dry climate in relation to urban geometry. Beccali, Strazzeri, Germanà, Melluso, and Galatioto (2017) reviewed some models evaluating thermal comfort in natural ventilated vernacular buildings, based on adaptive approaches.

Borong et al. (2004) concluded that sun shading and insulation are of great importance while natural ventilation is just considered as an auxiliary approach for the design principles of the traditional Chinese vernacular dwellings, based on the field measurements of the thermal environment parameters and a long-term auto-recorder of the indoor and outdoor temperature at four typical traditional vernacular dwellings at Wannan area in summer. Bouillot (2008) studied six Chinese vernacular houses in different provinces and found that the value and the diversity of the Chinese housing stock is due to the combination of the specific structure of the Chinese eastern climates, which creates the contrast of cold-dry winters and hot-humid summers, with the structure of the Ming t'ang, which contains the opposition of the yin and the yang. Liu et al. (2011)'s study interprets the characteristic of warm in winter and cool in summer in traditional Yaodong dwelling by measuring the indoor, outdoor and the wall's temperatures in winter and summer. The results show that the Yaodong thick wall effectively damps the external temperature wave and keeps a steady inner surface temperature, are the chief causes of warm in winter and cool in summer in Yaodong. Gou et al. (2015) focused on a qualitative analysis of ancient dwellings located in the village of Xinye, in the hot summer and cold winter region of China. According to the analysis, the climate responsive strategies of the dwellings are mainly focused on natural ventilation, sun-shading and thermal insulation, illustrated by different building aspects such as the building location, building group layout and orientation, internal space arrangement, opening design, among other variables. Soflaei, Shokouhian, and Zhu (2017) investigated the potential of traditional courtyard houses in Iran and China in responding to environmental challenges alongside social norms over a long period of time. The social and environmental dimensions of the sustainability as well as the main elements of traditional courtyard houses in Iran and China were identified.

Because of the advantage of vernacular building using passive ways to achieve thermal comfort and energy efficiency as mentioned above, this research will start with the investigation of a Chinese vernacular buildings in chapter 4. The next part of the literature review is an overview of passive cooling techniques.

3.2 Passive cooling techniques

Givoni (1994) identified “passive cooling systems” as the applications of various simple cooling techniques that enable the indoor temperatures of buildings to be lowered through the use of natural energy sources. Santamouris and Asimakopoulos (1996) identify passive cooling as the techniques which are based on the application of solar and heat control systems, dissipation of excess heat into low-temperature natural sinks, and the amortization of the heat surplus through the use of additional thermal mass in buildings. Passive cooling can broadly cover all the methods and processes that contribute to the control and reduction of the cooling needs of buildings.

Passive cooling techniques are broadly distinguished by their heat transfer in three categories: prevention of heat gains (reduce heat gains), modification of heat gains, and heat dissipation (removal of internal heat). The various techniques adopted for each of the three categories can be classified and are given in figure 3.1.

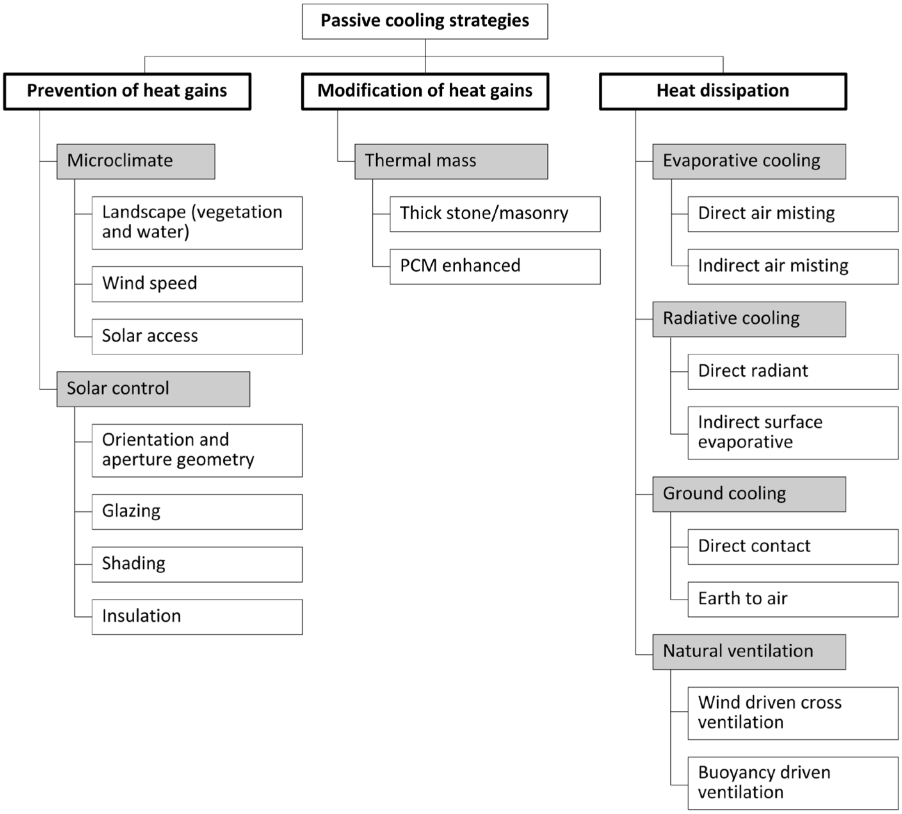

FIG. 3.1 Overview of passive cooling strategies (Geetha & Velraj, 2012; Valladares-Rendón, Schmid, & Lo, 2017)

3.2.1 prevention of heat gains

The first step to reduce the indoor heat gains is to prevent the heat load that comes from the sun and the outside thermal environment. The main approach to reduce the heat gain is solar control. Reducing the outside temperature is also an option, but this is described in section 3.3. where the passive cooling strategies at urban level are discussed.

Solar radiation reaches the external surfaces of a building in direct, diffuse and reflected form and penetrates to the interior through transparent elements. In general, the incident radiation varies with geographic latitude, the altitude above sea level, the general atmospheric conditions, the day of the year, and the time of the day. Solar radiation is the main factor that increases the building cooling load in summer, so controlling the solar radiation is important for a passive cooling strategy. Solar control denotes the complete or partial, permanent or temporary exclusion of solar radiation from building surfaces, interior or surrounding spaces (Geetha & Velraj, 2012). There are four major techniques for solar control.

1 Orientation

The orientation of an opening, combined with its size and tilt can change the solar gains passing through it (Santamouris & Asimakopoulos, 1996). Transparent components are essential to solar gains. The amount of heat that enters modern buildings by conduction via opaque areas of the envelope is usually small due to the small temperature differences in summer and the level of insulation that is already common in many countries (Santamouris, 2007).

Without the consideration of the wind direction for natural ventilation, Mazria (1979) defines the best orientation for the solar apertures of a building as one which receives the maximum amount of solar radiation in winter and the minimum amount in summer. Shaviv (1981) Studied the orientation of the glazing surface of a building and concluded that the main glazing surface should face south or southeast (northern hemisphere) to achieve the maximum energy saving of the building especially in countries with a hot and humid climate.

2 Aperture geometry

The size of the opening at each orientation should be defined according to the annual energy requirements of the specific building. This cannot be defined globally, but depends on the latitude of the place, the location, the functions and the architecture of the building. The concept of “window-to-wall-ratio” is commonly used to evaluate the opening area in the building envelop. It is identified as the percentage of the net gazing area to the gross wall area. For building’s energy performance, the optimal “window-to-wall-ratio” for hot and cold climates should be around 40% or less. A higher “window-to-wall-ratio” up to 90% can be accepted in cold climates, but only if the windows are well insulated, and in hot climates, only if the windows are well shaded (Valladares-Rendón et al., 2017). Tilt of the openings can also contribute to the shading effect since an outward tilt, facing the ground, restricts the direct solar gain (Santamouris & Asimakopoulos, 1996).

TOC

3 Glazing

The thermal properties of the glazing surface determine the amount of solar energy which penetrates into the interior of a building. Glazing with a low thermal transmittance can be achieved with specially treated glass such as: body-tinted glass with high absorptivity; surface coated glass with increased reflectivity; variable transmission glass; translucent glazing material; special sun-control membranes; temporary glazing coating; single-and double-glazed units with laminated glass incorporating blinds and louvers (Santamouris & Asimakopoulos, 1996). Research in the field of glazing systems received a boost, passing from a single pane to low-emittance window systems, and again to low thermal transmittance, vacuum glazing, electrochromic windows, thermotropic materials, silica aerogels and transparent insulation materials (TIM) (Geetha & Velraj, 2012).

4 Shading

Shading denotes the partial or complete obstruction of the sunbeam directed toward a surface especially the windows by an intervening object or surface. Shading on building façades controls the amount of solar radiation received by the building (Pacheco, Ordonez, & Martinez, 2012). The principal role of shading devices is to protect openings from direct solar radiation, while their second is to protect openings from diffuse and reflected radiation. Shading also can prevent visual discomfort. Solar gain through windows is a major component of the total heat gain of a building. Minimizing this heating source through the use of shading devices is therefore of primary importance in all types of hot climates (Givoni, 1994).

Shading devices can be classified as external shading devices and internal shading devices, or classified as fixed shading and adjustable shading. Fixed shading devices include horizontal overhangs, vertical fins, combination of horizontal and vertical elements closely spaced, balconies or internal elements like louvers and light-shelves. Adjustable shading devices are tents, awnings, blinds, pergolas, or internal elements like curtains, rollers and venetian blinds. In general, external shading devices have a higher performance than internal ones and fixed shading devices are economical solutions, as they do not require manual adjustments (Al-Tamimi & Fadzil, 2011; Freewan, 2014).

A suitable shading coefficient saves energy throughout the year (Yang, Li, & Hu, 2006). The shading coefficient is defined as the ratio of solar heat gain through a given fenestration system under a specific set of conditions to the solar heat gain through single glazing of standard 3 mm clear glass. One of the problems of establishing a fixed shading coefficient is that the angle of incidence of solar rays does not remain constant. Various research studies have been carried out to develop are liable method or system of calculating this shading coefficient (Pacheco, Ordonez, & Martinez, 2012). In hot climates, there are greater energy benefits with a high shading coefficient since heating gains are reduced.

Choice of the appropriate shading device from the wide range of fixed and adjustable elements depends on the latitude, sky conditions (the direct-diffuse-reflected solar radiation component), orientation, building type and overall design of the building. External shading devices are more effective as they obstruct the sun radiation before it reaches the interior of the building. In many cases fixed devices are preferred because of their simplicity, low maintenance cost and sometimes low construction cost. However, movable shading devices are more flexible as they respond better to the dynamic nature of the sun's movement, allow better control of the diffuse radiation and glare and, in most cases, causeless or negligible sun obstruction during winter (Santamouris & Asimakopoulos, 1996). The use of mobile shading systems is more beneficial in regards to natural illumination and to lower energy consumption.

5 Insulation

Insulation can efficiently prevent the building heat gains from the outside thermal condition. Belusko, Bruno, and Saman (2011) investigated the thermal resistance for the heat flow through a typical timber-framed pitched roofing system measured under outdoor conditions for heat flow up. However, with higher thermal resistance systems containing bulk insulation within the timber frame, the measured result for a typical installation was as low as 50% of the thermal resistance determined considering two-dimensional thermal bridging using the parallel path method. This result was attributed to three-dimensional heat flow and insulation installation defects, resulting from the design and construction method used. Translating these results to a typical house with a 200 m^2 floor area, the overall thermal resistance of the roof was at least 23% lower than the overall calculated thermal resistance including two-dimensional thermal bridging.

3.2.2 Modify heat gains

It is well-known that the thermal mass of a building (in the envelop, the inner wall, the floor, partition and other construction materials with a high heat capacity) is able to absorb heat and cold and store it for a period time before releasing it to the environment. Thermal mass, in summer, can regulate the size of indoor temperature swings, reduce peak cooling load and transfer a part of the absorbed heat to the ambient in the night hours. In addition, if there is a large enough temperature difference in the night, night ventilation enables the thermal mass to store the cold and release it in the early morning hours of the following day. The rate of heat transfer and the effectiveness of the thermal mass are determined by a number of parameters and conditions such as building material properties, building orientation, thermal insulation, ventilation, climatic conditions, use of auxiliary cooling systems and occupancy patterns (Balaras, 1996).

The thermal mass of a building can be achieved either through the construction materials or through phase change materials (PCM) in the building. Pasupathy, Velraj, and Seeniraj (2008) presented a detailed review on the PCM incorporation in buildings, and the various methods used to contain them for thermal management in residential and commercial establishments. Generally speaking, the PCM can be integrated with almost all kinds and components of building envelopes, but different application areas have their own unique configurations and characteristics (Geetha & Velraj, 2012).

3.2.3 Heat dissipation

Heat dissipation deals with the disposal of the excess heat of a building to a sink characterized by a lower temperature, such as the ambient air, the water, the ground and the sky. Effective dissipation of the excess heat depends on two main pre-conditions: (a) the availability of a proper environmental heat sink with a sufficient temperature difference for the transfer of heat and (b) the efficient thermal coupling between the building and the sink (Santamouris & Kolokotsa, 2013). There are four-well studied and developed techniques for heat dissipation: evaporative cooling, ground cooling, radiative cooling and natural ventilation cooling.

Evaporative cooling

Evaporative cooling is a process that uses the effect of evaporation as a natural heat sink. Sensible heat from the air is absorbed to be used as latent heat necessary to evaporate water. The amount of sensible heat absorbed depends on the amount of water that can be evaporated (Geetha & Velraj, 2012). There are two basic types of evaporative air cooling techniques (Santamouris & Kolokotsa, 2013): (a) the direct evaporative coolers commonly used for residential buildings. In this type of evaporative cooling the reduction of the temperature is followed by an increase in moisture content. Direct evaporative cooling is generally performed using a fan to draw hot outside air into the building by passing it over an evaporative pad. It is quite simple and cheap and is commonly used for residential applications. (b) the indirect systems where the evaporative cooling is delivered across a heat exchanger, which keeps the cool moist air separated from the room. This system does not cause an increase in air humidity. Indirect evaporative cooling usually incorporates an air to air heat exchanger to remove heat from the air without adding moisture. It is suitable for humid climate regions.

Ground cooling

It has long been known that the ground temperature changes more slowly than the temperature of the ambient air. The deeper one goes into the ground, the more the ambient temperature is attenuated, and at a certain depth the ground remains at an almost steady temperature level which is slightly higher than the yearly mean ambient air temperature (Santamouris, 2007). As a result, the ground can be used as a heat sink during the summer. Its cooling potential can be utilized directly when the building envelope is in contact with the ground (semi-buried buildings in hot summers), through horizontal earth-to-air heat exchangers or water-driven heat exchangers (Santamouris & Kolokotsa, 2013). The most common technique of ground cooling is the use of underground air tunnels, known as earth to air heat exchangers. Earth to air heat exchangers consist of pipes which are buried in the soil while an air circulation system forces the air through the pipes and eventually mixes it with the indoor air of the building or the agricultural greenhouse (Santamouris & Kolokotsa, 2013).

Radiative cooling

Radiative cooling is based on heat loss by long-wave radiation emission from one body towards another body of a lower temperature, which plays the role of heat sink. In the case of buildings, the cooled body is the building and the heat sink is the sky, since the sky temperature is lower than the temperatures of most of the objects on earth (Geetha & Velraj, 2012). Radiant cooling requires the roofs of building using heavy and highly conductive material (e.g. concrete) and insulation material. During the day, the external insulation on the roof minimizes the heat gain from solar radiation. The cooled roof mass can then act as a heat sink, and absorb, through the ceiling, the heat penetrating into and generated inside the building during the day-time hours (Pacheco, Ordonez, & Martinez, 2012).

Natural ventilation

Natural ventilation is achieved by infiltration (the term “infiltration” is used to describe the random flow of outdoor air through leakage paths in the building’s envelope) and or allowing air to flow in and out of a building by opening windows and doors (Santamouris & Asimakopoulos, 1996). In the process of passive cooling by natural ventilation, windows and doors, the large openings, are the main air flow paths as a result of the pressure differences due to wind and stack effect. There are basic functions of natural ventilation: maintain an acceptable indoor air quality and provide indoor thermal comfort. Provide indoor thermal comfort in buildings through natural ventilation is one important passive cooling strategy. For this objective, Givoni (1994) classified two types of natural ventilation: comfort ventilation and night ventilation. Comfort ventilation provides direct human comfort, mainly during the day. Night ventilation cools the structural mass of the building interior by ventilation during the night and closes the building during daytime, thus, lowering the indoor temperature during the day. The efficiency of night ventilation technique is mainly based on the relative difference between the outdoor and indoor temperatures during the night period. Various studies prove night ventilation effectiveness. Givoni (1998) carried out comprehensive experimental studies on night ventilation techniques in Israel and Pala, California. Based on the results in California, he argued that, if effective night ventilation can be ensured by the provision of exhaust fans, high mass buildings can be more comfortable, especially during the daytime hours than lightweight buildings, even in hot-humid regions. Kolokotroni and Aronis (1999) introduce some variables for the building such as building mass, glazing ratio, solar and internal gains, orientation and demonstrate that the optimization of the building design for night ventilation according to these parameters can cause an abatement of about 20-25% of the air conditioning energy consumption. Santamouris, Sfakianaki, and Pavlou (2010) pointed out that the application of night ventilation techniques to residential buildings may lead to a decrease of cooling loads almost 40 kWh/m^2/y with an average contribution of 12 kWh/m^2/y. A comprehensive review of night ventilation strategies is presented in (Santamouris & Kolokotsa, 2013). However, there are still some limitations of night ventilation. Such as the moisture and condensation control, particularly in humid areas. The most important limitation of night ventilation techniques is associated with the specific climatic conditions of cities. Increased temperatures due to the heat island effect, as well as the decrease in wind speed in urban canyons, considerably reduces the cooling potential of night cooling techniques (Santamouris, 2007).

1 Wind driven cross ventilation

Wind driven cross ventilation caused by the wind-induced pressure differences. Positive pressure is created on the building sides that face the wind whereas suction regions are formed on the opposite sides and on the sidewalls. This results in a negative pressure inside the building, which is sufficient to introduce large flows through the building openings.

It should be noted, orientation is very important for cross natural ventilation. Appropriate orientation can obtain enough wind velocity and wind rate to achieve the successful comfortable ventilation and night ventilation. Orientation for ventilation does not imply that the building should be perpendicular to the prevailing wind direction. Givoni (1994) mentioned that oblique winds at angles between 30 and 120 degrees to the wall can provide effective cross ventilation if openings are provided in the windward and leeward walls (Assuming the building lies in the wide location without influence by other buildings). However, when the best building orientation for sunlight control is in conflict with the best orientation for natural ventilation, which is the primary factor? It is different in arid or humid regions. In hot and dry climates, shading is of great or importance than ventilation; in hot and humid climates, on the other hand, emphasis is given to cross ventilation as the high humidity of the air creates discomfort for human beings (Santamouris & Asimakopoulos, 1996).

2 Buoyancy driven stack ventilation

Buoyancy driven stack ventilation caused by the stack effect occurs when temperature differences between a zone and the environment adjacent to it, be it another zone or the exterior, cause light warm air to rise and flow out of the warm zone, while cooler air flows in. Buoyancy-driven stack ventilation relies on density differences to draw cool, outdoor air in at low ventilation openings and exhausts.

3.2.4 Conclusion

Passive cooling techniques are significant to save energy for cooling buildings. These techniques, which have been neglected for a period, are getting more and more attention by researchers and designers in the context of sustainable design for energy conservation and reduction of emission of greenhouse gases. However, it should be noted that choosing a suitable passive cooling strategy for a particular project is important in order to save energy and provide a comfortable environment. The suitable strategy is decided by the climate condition, urban environment,

TOC

building type and style, material use and operation of the building. Additionally, the application of passive cooling strategies is strongly related to architectural design especially in the early design stages. The spatial design of urban morphology, building form and component can strongly influence the application. This will be discussed in the next section.

3.3 Passive cooling strategies related to urban spatial design

3.3.1 Urban morphology

In the field of urban planning and design, the study of urban morphology involves scrutiny and analysis of the urban fabric, and understanding and explanation of urban change in a wider sense. In its narrowest sense, urban morphology focuses on the study of the urban fabric of buildings, plots and street patterns (Marshall & Çalişkan, 2011). It refers to the organization of a group of buildings and the spaces between them in 3 dimensions. Urban planning focuses on the entire city, while, urban morphology focuses on the small scale of a city district. In a particular urban morphology, the position of neighbouring units and building form directly influence the accessibility to solar radiation from both the indoor and outdoor environment (Hachem, Athienitis, & Fazio, 2011; Kleerekoper, van Esch, & Salcedo, 2012; Taleghani, Tenpierik, van den Dobbelsteen, & de Dear, 2013). Orientation and neighbourhood patterns not only affect solar access but also airflow patterns and wind speed. Furthermore, the placements of buildings within the site and land use patterns strongly influence the outdoor air and radiant temperature of the microclimate created by city blocks (Taleghani et al., 2013). On the large scale, such as the city scale, it is hard to analyse the influence because of the enormous amount and complexity of the city buildings. But for the small scale such as the neighbourhood scale, through the development of computational simulations, it can be analysed and a lot of research has been done. Sanaieian, Tenpierik, Linden, Mehdizadeh Seraj, and Mofidi Shemrani (2014) reviewed the impact of urban block form on thermal performance, solar access and ventilation. Urban morphology relates to building block form, space between the building blocks and the arrangement of the two. The core problem is the arrangement. By the literature, most of the research of urban morphology which is related to outdoor thermal comfort and environment focuses on two aspects: street canyon and building group pattern (figure 3.2)

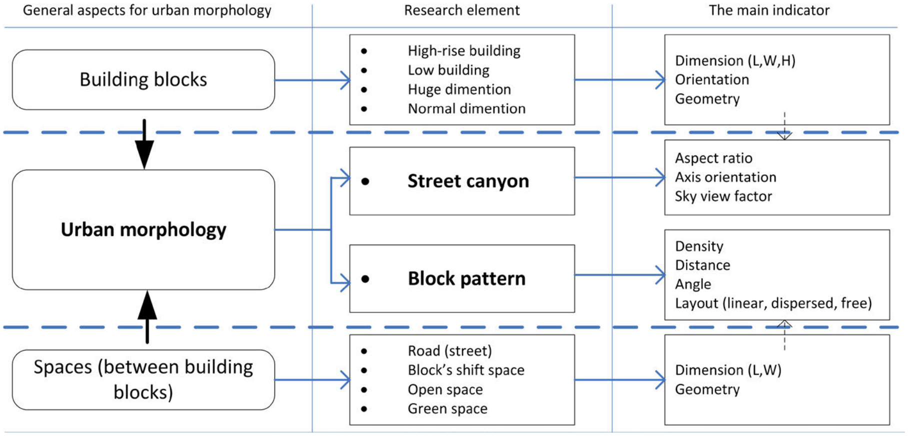

FIG. 3.2 Urban morphology related studies for outdoor thermal comfort and environment

Urban morphology to urban wind environment

The wind environment refers to the natural wind characteristics around buildings. The main indices to access the wind environment are the wind velocity, the wind direction, the wind pressure on the building (average pressure and pressure difference) and the wind field (the wind distribution in the vertical and horizontal direction which can be described by contours of air velocity magnitudes). The wind environment can be highly affected by building blocks especially in the urban region due to the variety of enormous building blocks. The main targets of the wind environment analysis are: outdoor comfort (such as the street, public space) and basic data for indoor comfort analysis.

In general, the higher the density of buildings in a given area, the poorer its ventilation conditions (Santamouris & Asimakopoulos, 1996). Kubota, Miura, Tominaga, and Mochida (2008) used a wind tunnel to test the relationship between building density and pedestrian-level wind velocity of several major Japanese cities. These results show that there is a strong relationship between the gross building coverage ratio and the mean wind velocity ratio. His wind environment evaluation for case study areas is performed using wind tunnel results. He proposed a method of guidelines for realizing an acceptable wind environment in residential neighbourhoods using the gross building coverage ratio (Kubota et al., 2008).

Urban or street canyon can influence the wind environment especially the wind velocity. Al-Sallal, Al-Rais, and Dalmouk (2013) simulated three cases in Al-Mankhool, Dubai, and concluded that in the modern urban pattern, the wind flow decreased when hitting the buildings, funnelled by the wider street canyons, then increased once again when the air flow is free stream. Wind velocities were more comfortable in wider street canyons. It was noticed that the wind speed increased substantially in open spaces such as parking areas and undeveloped plots. Fahmy and Sharples (2009) analysed urban canyons in a grid network, with three mid latitude orientations in Cairo. They found that although some very hot conditions were recorded, there were evident examples of more acceptable comfort levels and cooling potential for some orientations and degrees of urban compactness due to the clustered form with green cool islands and wind flow through the main canyons.

Building block patterns in the urban scale is also important for the urban wind environment. Zhang, Gao, and Zhang (2005) combined computational and experimental method to study the wind field around three different building block patterns. It was found that the wind environment for two improved arrangements with lower interval-height ratio is better than that for the reference layout with higher aspect ratios in terms of natural ventilation. The interference effect is more obvious for two improved arrangements than the reference one. The numerical results also show that changing the wind direction from perpendicular to the building facades to a 45 incidence angle has significant effect on the flow field for different configurations. Asfour (2010) used the CFD method to investigate the effect of the building grouping pattern on the resulting wind environment in the outdoor spaces and the resulting ventilation potential of these buildings. Several configurations of housing blocks exposed to different wind directions have been modelled and compared considering the hot climate of Gaza. It has been found that grouping pattern of buildings as well as their orientation with respect to wind has a dramatic effect on the resulting airflow behaviour and pressure fields. Configurations that contain a central space articulated by buildings and oriented towards the prevailing wind can offer better exposure to air currents and better containment of wind. Such configurations are recommended for better wind-driven ventilation, where the main design objective is passive cooling.

Urban morphology to solar control

The building blocks and neighbourhood morphology have the largest effect on the access of solar energy. A suitable design of the neighbourhood morphology can avoid the overheating of buildings. The major factors which affect solar access of buildings under a particular neighbourhood morphology are: urban density, orientation of building's façade and building outline and streets (ratio of building height to the street widths) (Sanaieian, Tenpierik, Linden, Mehdizadeh Seraj, & Mofidi Shemrani, 2014).

High-density urban neighbourhoods can minimize the building's solar exposure and provide outdoor shaded areas to avoid extra solar radiation through narrow streets and lanes. Many vernacular small towns proved that a narrow street is able to avoid the peak solar radiation in summer, especially in hot dry climate regions. Ali-Toudert et al. (2005) investigated the thermal environment of the old desert city of Beni-Isguen, Algeria. The results show that the vertical street profile is of prime importance in the resulting thermal sensation. Deep streets together with high thermal capacity materials mitigate the heat stress during the day. The high and heavy walls provide more shading and more heat storage, leading to lower surfaces temperatures. Andreou (2014) analysed the effect of parameters such as urban layout, street geometry and orientation on solar access and shading conditions in the Mediterranean, which strongly affect urban canyon microclimate through simulation and experimental measurements. It is demonstrated that the morphology of traditional settlements in the area examined, performs most positively and thus it can be claimed that lessons can be learned from vernacular architecture.

Niachou, Livada, and Santamouris (2008) conducted a study that focused on the experimental investigation of thermal characteristics of a typical street canyon, under hot weather conditions. The results indicate that the air temperature distribution inside a street canyon is a function of canyon geometry and orientation, as well as of the optical and thermal properties of building and street materials and ambient weather conditions. Giannopoulou, Santamouris, Livada, Georgakis, and Caouris (2010) investigated the impact of canyon geometry on the temperature regime and nocturnal heat island development in the very dense urban area of Athens, Greece. A clear increase of the median, maximum and minimum values of the cooling rates has been observed for decreasing aspect ratios.

In Chinese traditional small towns, the streets usually are narrow and surrounded with high walls. This avoids direct solar radiation to reach the bottom of the wall and keeps the air temperature of the street in a low level. Some researchers think that is the cool source for natural ventilation. Lin et al. (2002) have done long-term field measurements of the indoor and outdoor thermal environment in several typical Chinese Wannan traditional residential buildings in the summer. The results show that the “cool entry way” (very narrow alley between the buildings) provides enough shading to avoid the solar radiation. Chen and Zhong (2011) carried out a field study of thermal comfort on narrow alleys of three residential buildings and found that the main strategies of passive cooling can be concluded as narrow alley sunshade and ventilation, the ground and wall of the alley as heat sink and night ventilation. Furthermore, to verify the cooling effect of cooling alley in traditional settlement, Chen, Zheng, and Fu (2013) measured some cooling alleys in Quanzhou Shoujin Liao, Wannan Hongcun and Xitang Shuixiang. The results show that a cooling alley in tradition folk houses has an obvious effect on cooling, on the thermal buffer and acclimation by the way of self-sun shading, thermal storage of ground and wall as well as night ventilation. Gou et al. (2015) did a qualitative analysis of ancient dwellings located in the village of Xinye, in the hot summer and cold winter region of China, and one of the findings is that the streets form a narrow urban canyon offering mutual shading to the dwelling during sunny hours and create a comfortable thermal environment in hot summer.

3.3.2 Urban microclimate

Because of the urban morphology strongly influences the wind and solar environment of the urban space, the particular urban microclimate is largely decided by the urban morphology which is significant for passive cooling of buildings and outdoor thermal comfort. The urban microclimate is defined as a small-scale climate pattern within a particular region that the deviations in the climate are experienced from place to place within a few kilometres distance. The microclimate is affected by the following parameters: topography, soil structure, ground cover and urban forms (Santamouris & Asimakopoulos, 1996). The principal elements that characterize climate and weather are the air temperature, the solar radiation, the amount of moisture and wind. The definition of microclimate indicates that the microclimate is different in rural regions and human designed urban regions, which deeply influence the local microclimate. Generally, the influence of human urban design is characterized by higher ambient temperatures (the heat island effect), reduced relative humidity, reduced wind speed and reduced received direct solar radiation (Geetha & Velraj, 2012). Therefore, in an urban region, changing the urban morphology can change the microclimate and thus change the thermal environment of buildings. The general influence of urban morphology on urban microclimate is characterized by Givoni (1989):

- High ambient temperatures even during evening hours
- Reduced relative humidity, due to high air temperature and lack of sources of humidity
- Disturbed wind patterns with a reduction of air speeds which contribute to an increase in air pollution
- Reduction of the received direct solar radiation and increase of diffused radiation, owing to pollution particles in the atmosphere

Consequently, design strategies for improvement of the microclimate to obtain thermal comfort conditions during summer should focus on (Santamouris & Asimakopoulos, 1996):

- Solar protection of buildings and pedestrians
- Reduction of outdoor air temperature
- Wind enhancement, for both pedestrians and the ventilation of buildings
- Improvement of humidity levels
- Design initiatives should aim to:
- Provide protected spaces for outdoor activities which both improve outdoor comfort conditions and promote indoor comfort (thermal comfort indoor and outdoor)
- Contribute to reduction of the cooling load and to a lesser dependence of buildings on air conditioning (energy conservation)

3.3.3 Urban morphology and space syntax

As mentioned above, urban morphology concerns the urban fabric, the urban form and the urban structure which is formed by the building blocks and the spaces between them. To analyse and understand the urban structure, the street network, and further finding the patterns of the city and the social meaning, some qualitative and quantitative methods are invented. Marshall (2005) developed the classification system for street morphologies analysis, and Berghauser Pont and Haupt (2009; 2010) developed the integrated density approach. Space syntax is one of the important theories and methods which was first proposed by Hillier (1999). Space syntax theory considers the city or architecture as a spatial system, thus the analysis turned attention away from the geometrical notions of spatial features, as described in figure 3.2, in the study of city or architecture, emphasising instead the topological relationship between the spaces. A set of techniques were proposed to analyse the spatial structure or the configuration of the city or architecture to foresee their functional outcomes, especially the human activities and their social meaning.

In the space syntax method, the spatial configuration and the social logic of a particular urban or building space can be visually represented by a topological network, a “justified graph”, in which every space in a certain spatial configuration is represented as a “node”. In the justified graph, a particular room of the spatial configuration is selected as the root node, and the spaces in the graph are then aligned in levels above, according to how many spaces one must pass to arrive at each space from the root node (Hillier, Hanson, & Graham, 1987). Figure 3.3 shows a typical example to explain the logical relations between spaces in space syntax. In the first column, there are three layouts of buildings. They have the same shape and the same number of rooms. The only differences are the openings between the rooms. The corresponding pictures in the second column show the spaces as black colour as the focuses in space syntax. The third column shows the “justified graph” of the three layouts in terms of the topological relationships of the spatial configuration. As we can see, from the outside space (the root), layout (a) has a “deep tree” form; layout (b) has a “narrow tree” form; and layout (c) has a “ring” form. The spatial configuration of the three layouts is totally different even they have the same shape and numbers of rooms. Figure 3.4 shows another example of using “justified graph” to analyse the spatial structure. There is a layout with ten rooms. If we chose the different internal space as the root space in terms of room 1, 10, and 5, there is a large difference in the “justified graph”. That means the topological relationship of the layout is different when the graph is justified from a different space.

TOC

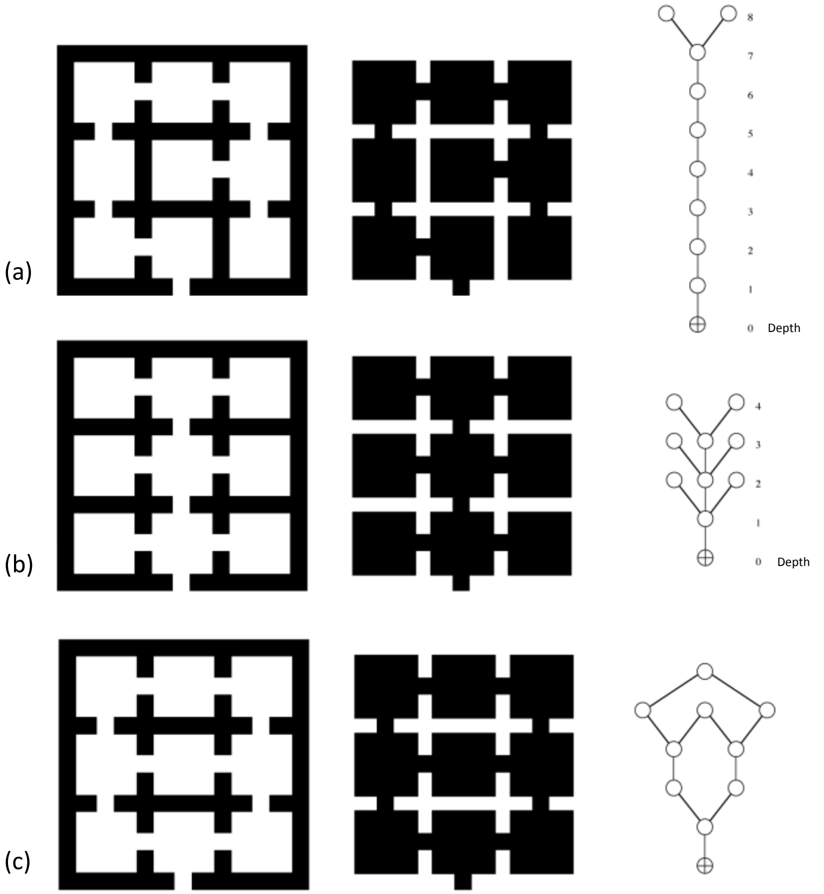

FIG. 3.3 A typical example to explain the logical relations between spaces in space syntax (Hillier, 1996)

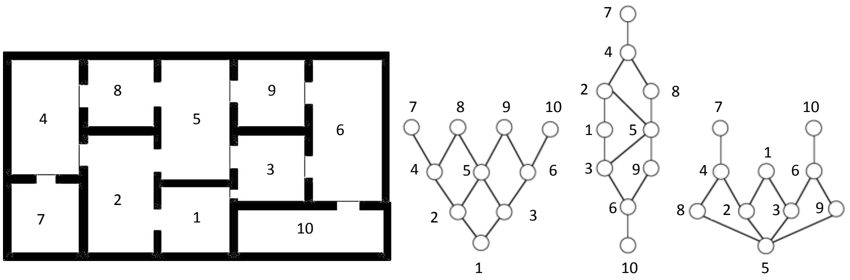

FIG. 3.4 The different “justified graph” from different root within a same layout (Hillier, 1996)

From a justified graph, four major indices can be determined to evaluate the spatial configuration properties in terms of permeability or accessibility.

1. Connectivity value: the total number of nodes which connected to one chose node. The bigger the node's connectivity value, the better the permeability of the space in which the node is.

2. Control value: the control values are found by assigning each node's connection a value of 1. The control value of node "n" is the total connections received by node "n" during this operation. A bigger control value of a node means this node can control or influence more adjacent nodes.

3. Depth value: if it is 1 depth from one node to adjacent node (it is directly accessible to it), the shortest distances (minimum depth) from one node to another node is the depth of the two nodes. The total depth (TD) of node "n" is the total of the shortest distances from node "n" to all other nodes in the systems. The mean depth MD for a node "n" is the average depth from node "n" to all other nodes. If "k" is the total number of nodes in the spatial system, then MD=TD/(K-1).

4. Integration value: it is related to the "Relative asymmetry". The relative asymmetry (RA) describes the integration of a node with the value between 0 and 1. A low value describes a high integration. RA is calculated by the formula RA=2(MD-1)/(K-2). The integration value is 1/RA. The integration value is the most important index because some researchers indicate that it is closely related to human spatial behaviour. If a node's integration value is larger, the permeability and accessibility of this node is better.

Of the four indices identified above, connectivity and control describe the local spatial relationship in terms of one space to the adjacent spaces, while depth and integration trace the global relationships between one space and all other spaces involved in the whole system.

Based on the major parameters mentioned above, several computer programs have been development to implement these approaches to calculate the basic parameters and show them visually. The DepthmapX-one graph-based representations and measures program (Turner, 2001) is one of the most important platforms for space syntax analysis. Convex and axial analysis, isovist and VGA analysis, as well as segment analysis are the methods involved in this program (Al_Sayed, Turner, Hillier, Iida, & Penn, 2014). The axial and segment analysis are more suitable for the analysis at the urban scale. The convex analysis is suitable for the building scale and isovist and VGA analysis are suitable for both urban and building scale.

Over the past decades, space syntax and various related theories and methods, such as Isovist (Benedikt, 1979) and Prospect-refuge (Appleton, 1975), have been applied in urban and architectural design to investigate the relationship between spatial features and underlying social behaviour, for example movement patterns, street network study, way-finding, security, living style at the urban scale (Choi, Kim, Oh, & Kim, 2006; Hillier, 2009; Hillier & Shinichi, 2005), and building scale (Choi, 2013; Dawes & Ostwald, 2014; Franz & Wiener, 2008; Hillier et al., 1987; Julienne, 1998). The theories and methods have undergone a great deal of development and have been verified through decades of research. The space syntax method provides the possibility for urban planners and architects to explore their ideas, to understand the possible effects of their design and to show how their designs work (Dursun, 2007).

3.4 Passive cooling strategies related building spatial design

The appropriate architecture form has significant potential for passive cooling of buildings via solar control and natural ventilation. The strategies of controlling building form and shape for passive cooling have been proved effective by the architectural practices of vernacular tradition buildings and contemporary buildings. Due to the close relationship with architectural innovation, it is the real strategy that architects can and should adopt in the early design stages. In the next sections, the building shape, building layout, building opening and building element are reviewed on passive cooling.

3.4.1 Building shape

The shape of a building influences the amount of solar energy that enters the building as well as the total energy consumption of the building (Tang, 2002). The optimal shape of a building is widely considered to be the one that loses the least heat in winter and gains the least amount of solar irradiation in summer. The building volume is approximately related to the thermal capacity, the ability to store heat. The exposed surface area is related to the rate at which the building gains or loses heat (Santamouris & Asimakopoulos, 1996).

The main variables related to building shape, which influence heating and cooling loads, are building form, compactness index and the shape factor. The compactness index is the ratio between the volume and the outer surface of the building facade. It is related to the building's capacity to store heat and avoid heat loss through its facade. A very compact building is one that has a high volume to surface ratio, where the surface exposed to possible heat losses or gains is as small as possible. The shape factor is the ratio of building length to building depth. Along with orientation, this factor defines the percentage of the facade exposed at each cardinal point (Pacheco et al., 2012).

In cold climate regions, high form compactness is preferable since it can reduce the heat loss in cold winter. In hot and warm climate regions, the situation is more complex. In hot arid climates, the building should be compact-the surface area of its external envelope should be as small as possible to minimize the heat flow into the building (Givoni, 1994). In a hot humid climate, ventilation is the most effective way to minimize the physiological effect of the high humidity. A spread-out building allows better natural cross-ventilation than a compact one by providing more wall area, and in more directions, for catching the winds. Buildings should maximize the area of the exposed surfaces in a hot humid climate (for free-running buildings without air conditioning). Evans (1980) presented a summary of requirements for conditions of optimal heat gain and heat loss for the case of a simple rectangular building form in different climates. Generally, for free-running building, volume-to-surface ratio is very important for the heating energy consumption in winter than cooling energy consumption in summer.

It is argued that restriction of the optimal shape could be relaxed by adopting several energy saving measures, for example extra insulation, allowing in this way architectural freedom in the choice of the building's form. Building's summer thermal performance could be improved by giving more importance to the materials used and to the architectural elements such as shading devices, wind walls and courtyards. To thermal characteristics, forms should be explored which enhance wind channelling into the building and permit ventilation throughout the occupied spaces (Santamouris & Asimakopoulos, 1996). Some researchers studied the relationship between building shape and thermal performance and energy efficiency (AlAnzi, Seo, & Krarti, 2009; Depecker, Menezo, Virgone, & Lepers, 2001; Liu, Lin, & Peng, 2015; Wang, Rivard, & Zmeureanu, 2006; Yi & Malkawi, 2009). Their objectives were to find the optimal building shape for energy efficient building design.

3.4.2 Building layout

The indoor space or layout determines the ventilation conditions. An open plan combined with a proper distribution of openings is preferable for undisturbed ventilation in the interior. As practical needs require separation of spaces, restriction of air-flow paths should be avoided and the positioning of partitions should help channelling the air through the occupied space (Santamouris & Asimakopoulos, 1996). In literature, the studies that focus on the building layout for cross ventilation is rare.

3.4.3 Building opening

A window is a very important component in the building envelope, providing enough sunlight, solar heating in winter, ventilation and visual contact with the outside. For sunlight, the window-to-floor ratio is the main index to consider in design. For solar gain and heat loss in winter, the window-to-wall ratio (the percentage of glazing area to the wall area of a building façade) is the most important index to evaluate suitable window size (obviously, material of glass and window frame are also important factors, but this is another issue). For visual needs, modern building prefers a window as large as possible as we see from the large amount of glass that is used in the façades of modern buildings. For passive cooling, ventilation and solar protection are the main issues of window.

In hot and humid regions, openings play a major role in determining the thermal comfort of the occupants as the location and size of the window determine the ventilation conditions of the building. In this respect, large openings in all walls can provide the design solution for effective cross ventilation. However, solar radiation can penetrate directly through un-shaded openings into the interior of the building and elevate the indoor temperature above the outdoor level. Therefore, utmost care should be taken in ensuring that all openings in the envelope of the building are effectively shaded (Givoni, 1994). In this case, window size, location and shape are the main factor to the efficiency of ventilation. Some research has focused on the optimization of window size for cross natural ventilation (Almeida, Maldonado, Santamouris, & Guarracino, 2005; Visagavel & Srinivasan, 2009; Yin, Zhang, Yang, & Wang, 2010). Another important issue is the summer thermal comfort and occupants' behaviour related to windows (Fabi, Andersen, Corgnati, & Olesen, 2012; Fabi, Andersen, Corgnati, & Olesen, 2013; Jeong, Jeong, & Park, 2016; Liu et al., 2012; Liu et al., 2012).

TOC

3.4.4 Building “elements”

Courtyard or patio

A courtyard is an old building element used in the vernacular traditional buildings around the world, especially in Asia, North Africa, South America, the Middle East and South Europe and which is still present in contemporary buildings. These significant outside spaces which are partly or completely surrounded by buildings or walls and are always combined with the landscape contribute to the architectural aesthetics and the building performance. The primary function of a courtyard is to provide light and ventilation for relatively large buildings which have a large depth and width. Traditionally, courtyards are used in both residential and public buildings. But now, as more families living in the apartments and small houses, courtyards are used more in public buildings. A courtyard can influence the building energy consumption and thermal comfort in two ways. Firstly, a courtyard provides sufficient shadow in summer, thus avoiding solar radiation and reducing the cooling loads. Secondly, a courtyard improves the natural ventilation and provides comfort ventilation and nocturnal ventilation. For low buildings with a courtyard, cross ventilation is the main type of natural ventilation and for high buildings, stack ventilation can also have a contribution. Plants and water (such as a ponds) in the courtyard also play a very important role in passive cooling.

A lot of research have investigated the orientation, geometry and use of vegetation and water of courtyard for thermal comfort and energy efficient which can be categorized into ventilation performance (Rajapaksha, Nagai, & Okumiya, 2003; Sharples & Bensalem, 2001) and solar performance (Aldawoud, 2008; Ghaffarianhoseini, Berardi, & Ghaffarianhoseini, 2015; Muhaisen, 2006; Muhaisen & Gadi, 2005, 2006; Safarzadeh & Bahadori, 2005; Soflaei, Shokouhian, Abraveshdar, & Alipour, 2017; Taleghani, Tenpierik, & van den Dobbelsteen, 2014a; Taleghani, Tenpierik, van den Dobbelsteen, & Sailor, 2014; Yang, Li, & Yang, 2012) in hot arid climate and hot humid climate through experiment or numerical analysis.

Atrium

An atrium is a relatively large space, usually with a glass roof, in the centre of a building. Its function in lighting and ventilation is similar to a courtyard, but unlike the courtyard, it is an indoor space. The glass roof of an atrium can lead to a high indoor temperature difference and enhances the stack ventilation in the building. Because of its huge volume, atria are usually applied in public buildings. A good atrium design will specifically bring natural lighting into the interior spaces of the building and therefore minimize the dependence on artificial lighting and reduce the energy demand for space conditioning.

Aldawoud (2013) put forward a study where the thermal performance of various shapes and geometries of atriums in buildings is examined under various conditions. The goal was to assess the impact of the atrium shape on the building total energy consumption and to identify the most energy-efficient atrium design. The results of this study indicate that in general, the total energy consumption of the narrow, elongated atrium or the rectangular atrium with high ratio of length to width is significantly greater than the square shaped atrium.

Transitional space (semi outdoor space, buffer zone)

The semi-outdoor space, which is also called transitional space or buffer space, is a space featuring a semi-enclosed wall or roof. It can connect the indoor spaces and outdoor spaces flexibly. The terrace, balcony, veranda and outside corridor are the main transitional spaces. For passive cooling purposes, the transitional space is generally regarded as one shading component for solar controlling of building. Therefore, the solar control function of semi-outdoor space was discussed in the shading part. The semi-outdoor space is also an important space for occupants' activities in the hot and humid climate regions in summer. In this space, occupants can enjoy more comfortable ventilation by catching the winds in various directions. And the thermal sensation is much better than in the compact indoor environment. The presence of transitional spaces provides the occupants with more choice in spaces with different thermal environments

3.4.5 Conclusion

Summarizing the passive cooling strategies related to building spatial design, some conclusions can be obtained:

1. Solar control and natural ventilation are the main passive cooling techniques used in the building spatial design.
2. The microclimate in building scale has not been paid enough attention.
3. Courtyard is broadly studied and building shape is focused in rising, however, translational space and building layout has not been paid enough attention.

TOC

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