The Application of Downdraught Cooling in Vernacular Skywell Dwellings in China

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Abstract. Traditional skywell dwellings in the hot climate regions of China represent an important cultural heritage. Achieving indoor comfort meeting occupants’ expectations, can contribute to the preservation of this unique traditional architecture. Improvement of ventilation and indoor temperatures through natural, sustainable and low impact solutions is an opportunity in achieving building thermal comfort in these traditional dwellings. The existence of skywells provides a good opportunity for the incorporation of downdraught cooling with minor interventions, and thus by avoiding extensive ductwork, saving energy and improving indoor temperatures, it can contribute to the preservation of traditional dwellings. Applicability of downdraught cooling, the history of traditional ventilation solutions, layout and space features of skywell dwelling are discussed and the way of incorporating downdraught cooling as an alternative to air-conditioning into these buildings is investigated.

1. Introduction

Today’s worldwide conventional cooling systems are based on air-conditioning, which is recognized throughout the world as a major source of Building Energy Consumption. The extensive use of conventional air conditioning is a source of energy supply problems especially significant during summer peak loads in the USA, India and China and in other economies as well. Due to electricity disruption problems, furthermore high investment loads in expensive electricity back-up generating equipment, alternative refrigerating solutions as well as more radical alternatives to air conditioning are in the focus of research. Various systems, such as Evaporative coolers, techniques exploiting night sky radiation, for example roof ponds and Downdraught cooling (DC) showed encouraging results in hot climate conditions to become viable sustainable alternatives to conventional air conditioning. Downdraught cooling (DC) systems differ from conventional cooling systems in that the primary mechanism for distribution of cool air is either by buoyancy or wind assisted natural ventilation. In the past decade downdraught cooling has been proven as a feasible alternative and a number of pioneering buildings implementing this novel technique have emerged around the world such as the Torrent Research Centre in India, the Stanford Ecology Centre in the USA and the Habitat Research & Development Centre in Namibia to mention a few. [1] The focus of most of the research was to incorporate this technology in either new built buildings or to implement it during refurbishment, mostly in offices or other public building. However due to the fact that extensive ductworks characteristic for conventional air conditioning are extent, downdraught cooling can be a good alternative in vernacular architecture and in historic buildings, where the preservation of the original interior is important.
2. Historical background
Before modern mechanical means for obtaining thermal comfort appeared, people in the hot and dry or humid climate areas, such as the Mediterranean and the Middle East, were needed to develop ways to cool their houses using natural sources of energy. [2] Traditional ways use different techniques (ground cooling, wind towers, cooling based on evaporation of water, fountains and courtyard house) [3], [4]. The tradition of cooling in the areas mentioned, was sophisticated and highly developed as early as the 15th Century BC. A cardinal component of achieving thermal comfort in the past was ensuring adequate natural (passive) ventilation. For example, Middle Eastern and Mediterranean country houses are well-known for their cooling properties. Constant air movement is achieved through temperature difference between a small, well shaded and cool courtyard and a large and hot one. The enhancement of air movement through ventilation towers has its roots also in the past. In Iran and the countries of the Gulf, a specific type of ventilation tower was developed, which functioned as wind catcher and in conditions with little or no wind the shaft acted as an air stack after heated up by the sun. Natural ventilation was in many cases combined with the cooling effect of evaporation. One of the widest spread methods in traditional architecture was the use of fountains. They can be found in arab houses as well as in southern Europe. Other examples include the mashrabiya, a cantilevered space with an opening covered by lattice, where small water jars were placed [2] or the mazaria cooling jars used in rural areas of Upper Egypt [5]. As Hassan Fathy [2] emphasizes that traditional solutions in architecture should be researched and understood in more detail, and they should be adapted to be suitable for modern requirements.

China is a country with many ethnic culture, it has a long history and a vast territory. During the thousands of years of its history an extensive amount of different types of residential building have evolved. Over the recent decades, due to extensive urbanization and its promise to accomplish a better living environment, modern architecture became more widespread and is replacing traditional dwellings. Traditional vernacular dwellings are part of the cultural heritage and the ecological thinking and technical solutions used are a significant knowledge source for the future development of sustainable, climate and terrain adaptive new buildings.

The adaptability to modern life and comfort of a traditional vernacular dwelling must be improved. People due to the technological development become more and more accustomed to very stable and comfortable indoor conditions. Ventilation is an important measure of thermal comfort. However traditional ventilation techniques alone are mostly not able to achieve the expected level of comfort, as also shown in the study of Duan, Ford and Lau [6], thus improvements should also focus on enhancing indoor ventilation conditions, which is an area what needs to be researched in more detail. One typical traditional design element for ventilation and lighting purposes in China is the skywell, which seems suitable to an easy incorporation of downdraught cooling without major interventions, which is the focus of this study. By understanding these techniques and combining them with new sustainable solutions the results may satisfy occupants requirements, while preserving the cultural heritage and saving energy.

3. Downdraught cooling in China
Downdraught cooling is an energy and cost saving alternative to conventional air conditioning. It relies on the effect of gravity on a body of cold air to create a downdraught, and thus to move the air from the source of cooling within the building. [1] Downdraught Cooling types are differentiated according to the source of cool air, which can be as ‘passive’ or ‘active’. When cooling of the air is achieved through the evaporation of water, it is labelled as Passive Downdraught Evaporative Cooling or ‘PDEC’. In warm and humid conditions, Active Downdraught Cooling (ADC) can be the alternative to conventional air conditioning. Cooling occurs by using chilled water cooling coils or panels, meaning the strategy relies on mechanical cooling. In areas with mixed climate conditions during the summer months hybrid downdraught cooling can provide the solution. A hybrid downdraught cooling system (HDC) combines both ‘passive’ and ‘active’ downdraught cooling techniques. This cooling strategy uses evaporative cooling in hot and dry climate conditions but the
chilled water cooling coils take over in warm and humid conditions. [1] The climate zone classification and climate applicability maps of China (Figure 1) provide a primary assessment about the opportunity in China of using downdraught cooling as an alternative or a complement to conventional air conditioning systems.

Based on the maps seven climate zone for downdraught cooling were defined with suggested cooling strategies. The three climate zones (dry, moderate humid and high humid) identified by the WBT depression were divided into two sub-zones with the difference of cooling degree hours (hot and warm).

In the hot climate zones PDEC, HDC and ADC integrated with other passive cooling strategies were proposed to address the cooling load. While in the warm climate zones, because the cooling load is not as high, the combination of downdraught cooling and natural ventilation was proposed. The only places where the use of downdraught cooling is not recommended are the temperate summer zones on the maps. Here, natural ventilation and high thermal mass can be relied on to meet the cooling load. The maps clearly show that downdraught cooling can be applied in a significant part of China and thus can represent a significant energy-saving potential. [7]

4. Vernacular architecture and ventilation strategies in China

China’s different regions have different natural conditions and cultural background, which is reflected by diverse vernacular dwellings all over the country. In northwest regions of China, Gansu, Xinjiang and the Ningxia provinces, the traditional building design responds to the hot and dry climate. In Xinjiang province, the traditional houses have a strong response to climate and are using various techniques to encourage cooling. solar shading, thick adobe wall, small windows, courtyard for ventilation cooling and evaporative cooling. The cooler air from the courtyard circulates across the surrounding rooms, where the occupants appreciate both the lower temperature and the air movement and exhaust from the light well called ‘A Yi Wang’, which functioned as summer living and communication space, providing day lighting and ventilation. (Figure 2.) Buildings in the areas of Guanxi, Guizhou, and Yunnan with hot and humid climates, are typically open skeleton structures with ventilated, high-ceilinged rooms. Building materials are lightweight materials such as bamboo, fibres or leaves to ensure ventilation and make the best possible use of wind. Floors and shaded terraces are raised above the terrain to protect against flooding, moisture and small animals and to
provide ventilation through the floor. Houses may also be placed on water to make maximum use of the cooling caused by evaporation.

Figure 2. (a) Ventilation strategy of Ayiwang, (b) Ventilation strategy and of an open skeleton structure [8]

These two examples show the differences of adaptation to climate, but there are also some common similarities in building layouts deeply rooted in culture and design philosophy. Courtyard houses can be found all over the country and are a common feature of Chinese vernacular architecture. It has a 2000-year old history and the philosophy of this layout can be traced back to the Tao principles and the Ming t’ang, the calendar house [9]. Plans are usually symmetrical and rectangular. The core of the layout is the courtyard, with rooms around it on three or four sides, but climate conditions and differences the way of life in different regions have led to a large variety of plans and elevations. From the northeast to the southwest, the courtyard area gradually becomes smaller and are known as sky well. Sky well houses have relatively closed courtyard formed by closely spaced buildings two to three storeys high. The skywell has a rather small opening to the sky through the roof space. Types of skywell dwellings, varying in layout, can be seen in Figure 3. These enclosures help in temperature regulation and in assisting natural ventilation. Northern courtyards face the south direction and are more open, this allows the exposure of the building to the sun and keeps the cold northern winds out. Southern sky wells are smaller and their functions include the collection of rain water from the roof tops, limiting the amount of sunlight and also serve as vents for rising hot air, which draws cool air from the lower stories of the house and facilitates the exchange of cool air with the outside. The effect of skywells on ventilation can be enhanced further, or with some additional design elements they offer the possibility to introduce some type of downdraught cooling.

Figure 3. Skywell dwelling diagrams and plans (Source of illustration: [8] )

5. Downdraught cooling integration
Studies of building typology and morphology undertaken to assess the applicability of downdraught cooling identified three levels of intervention required on existing buildings to be able to apply downdraught cooling. Minor intervention, Intermediate intervention and Major intervention [1]. The crucial factor in the feasibility of integrating downdraught cooling to existing buildings is the existence or the possibility to add a light well. (Figure 4)
According to the definition in the research Minor intervention will be applied where light wells or shafts could be utilized as DC towers, (Figure 4.b) which in this case is always present in the skywell houses. However existing skywells have certain requirements to fulfil in order to allow the installation of downdraught cooling with only minor intervention. Dimensions should not exceed 3-4 meters and the distance of the light well to an external wall should not exceed 12 meters. Rooms should be connected to the skywell through an opening (windows or doors) and opposite side of the skywell there should be openings for exhaust, for example manually operated windows. [1] Most of the skywell houses will fulfil these requirements, but individual assessment is necessary to establish accurate intervention strategies. Figure 5 shows the proposed interventions and airflow strategy for a typical skywell house.

An air inlet structure can be designed using steel and glass to minimize visual impact and to clearly separate old building from modern extensions, following recent trends preferred in historical building conservation. The air inlet should be designed considering the shape and angle of the existing roof structures, and if possible using it to enhance driving air towards the cooling source. The design could easily incorporate features for collecting rainwater and thus not losing this function of the skywell. Some type of movable shading can also be added, to allow the control of solar heat gain.
entrances, windows and staircases can be used as exhausts, but in very closed structures opening air vents on main walls should be considered. The source of cooling should be chosen according to climate conditions, based on the applicability maps and climate classification, but in the case of installing water nozzles, height of the skywell should be not less than 3 meters to allow evaporation.

6. Conclusion
Skywell dwellings represent an important heritage of Chinese architecture and thus should be preserved, however improving them is necessary to provide thermal comfort for the occupants. Downdraught cooling is a feasible alternative to conventional air conditioning in a significant area of China. General structure and plan features of skywell dwellings indicate that by minor intervention the application of Downdraught cooling is a feasible strategy to address the need for cooling and ventilation. Energy savings and conservation of original indoor design are among the benefits of such cooling strategies. However further research should be done, and the theory should be tested by empirical studies.

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8. References
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