Indoor Natural Ventilation Using Evaporating Cooling Strategies in the Egyptian Housing: A Review and New Approach

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***Abstract*—Houses in Egypt are often designed without sufficiently taking the climate into account. Factors such as the urban environment, site characteristics, orientation and architectural design of the building, choice of building materials, etc. are not emphasized. Consequently, buildings often have a poor indoor climate, which affects comfort, health and building efficiency. One reason why buildings are poorly adapted to the climate is lack of knowledge among architects, planners and engineers. This review focuses on two main areas of research. First, the housing problem in terms of thermal comfort, indoor environment problem. Second, present solutions, strategies and the future research. Moreover, this review found that the problem of achieving thermal comfort is not fully understood but there are new integrated strategies that can be developed which use low cost passive cooling strategies to reduce the heating loads. Besides, it is suggested to further study the optimization and the control strategy of such integrated system in Egypt.**

***Index Terms*—Thermal comfort, natural ventilation, evaporating cooling.**

I. Introduction

Thermal comfort is the state of mind which is satisfied with the thermal environment [1]. In other words, it is the conditions in which a person would prefer neither a warmer nor cooler surrounding environment [2]. Thermal comfort is maintained when the heat generated by human metabolism is allowed to dissipate, thus maintaining thermal equilibrium with a person surroundings. It has long been recognized that the sensation of feeling hot or cold is not just dependent on air temperature alone. Also, the environmental conditions required for comfort are not the same for everyone, so it is difficult to satisfy everyone in a space because there are large variations from person to person.

The aim of cooling a building in a hot climate is to provide an artificial, thermal and environment comfortable. The human body generates heat at a rate depending on its activity level. If the rate of the associated heat loss to the environment is less than what the body needs to achieve by convection and radiation, then perspiration occurs, and this indicates that the body is in a state of thermal discomfort [3].

Buildings, energy and the environment are key issues facing building professionals worldwide. Bioclimatic building design is one strategy for sustainable development, as it contributes to reduce energy consumption, ultimately mitigating air pollution and greenhouse gas emissions, but also providing comfort for occupants [4]. Also, any environmental damage or current climate change concerns are directly linked to human activity. In relation to the criterion of good energy efficient design and the issue of healthy built environments, natural ventilation appears to be a very attractive solution to ensure both good indoor air quality and acceptable comfort conditions in many regions [5]. It is important to keep in mind that the fundamental objectives of building design to provide an efficient, comfortable and healthy environment [6]. Therefore, this paper will review present climate problem in Egyptian housing and the present solution to achieve thermal comfort with the help of natural ventilation and new approach for using natural ventilation with evaporating cooling strategy to achieve comfort and low energy consumption.

II. Climatic Problem and Indoor Problem in Egyptian House

A. Climate Analysis

Egypt is part of the world's hot arid climatic zone and occupies the northeastern corner of the African continent and Sahara desert. It is a unique location at the crossroads of East and West, Africa and Asia. Its geo-location is 30º 06 N, 31º 25 E [7]. In term of climate, Egypt has a significant variation in the climatic conditions. The Egyptian organization for energy conservation and planning [EOECP] divides the country into seven different climatic design region. In turn, This creates great variations in the requirement of climatically response building designs [8]. According to Koeppen's climate classification [9]. Most parts of Egypt are occupied by the Sahara desert, which represents the most extensive arid area on the planet. Desert areas have different characteristics than other areas because of the large temperature difference between night and day, scarcity of rain and strong glare reflected from the desert land. The low rate of evaporation in the region causes low humidity winds, and the air becomes loaded with dust resulting from the rough landscape. According to the National Oceanic and Atmospheric Administration [NOAA], temperature and humidity level of cities in Egypt were provided by the World Meteorological Organization [WMO]. The mean average temperature for Cairo, Alexandria, Asswan and Asyut are

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21.38°C, 19.99°C, 25.88°C and 21.88°C respectively. The mean average humidity level are 55.75%, 67.92%, 26.17% and 38.33% respectively. It appears that the maximum temperature for Cairo, Alexandria, Asswan and Asyut in January is 18.8 °C, 18.4 °C, 21.0 °C and 19.3 °C, with relative humidity 59 %, 69 %, 40 % and 52 %, and in July are 34.6°C, 29.9°C, 41.0°C and 36.5°C with relative humidity of 61%, 71%, 18% and 32% respectively [10].

B. Indoor Environment Problem in Egypt

The climate problem in Egypt began to be more evident when the Egyptian government constructed number of new communities in the desert surrounding existing cities without considering any importance for the climate conditions and comfort of occupants [11,8]. The public housing projects in new cities were designed as fixed prototypes that are being built all over the country regardless of social life style and climatic conditions [8]. The intensity of solar radiation and the clarity of the sky are the main reasons for the extreme levels of heat encountered in Egypt. Measurements show that there is a significant amount of heat gain into new dwellings that causes discomfort among the users, especially in the summer season [12,13,8,14,15]. On other hand, new housing is poorly adapted to the climate because architects lack of knowledge and adequate design tools. Furthermore, experience from traditional architecture, which was fairly well adapted to the climate, is often lost or difficult to adapt to modern techniques and society.

In Egypt's hot-dry climate, opening windows during the day time can significantly increase the indoor temperature. The desired higher air speed can be provided in this case by using fans [16]. However the financial resources of the average family in Egypt is considerably limited and thus the ability to acquire and run air conditioning units is limited and, if found, are only used during very hot periods. As a result, air conditioning would have to be replaced by natural ventilation for the removal the building heat load for thermal comfort. It is well known that natural ventilation can be very effective in maintaining acceptable internal thermal comfort in such climatic context [16, 17].

III. Researches for Solutions and Strategies for Indoor Environment Problem

Most of the new urban settlements near cities are poorly adapted to the prevailing climate and are not a sustainable community. Therefore, many problems appear inside these building. A considerable amount of literature has been published on building and climate relationships and studies to find climatic strategies for buildings and received substantial attention over the last few years in Egypt especially natural ventilation as one of many passive design strategies that should be considered when designing buildings in hot dry climates. A lot of previous research investigated climatic responsive design. This situation calls for the importance of investigation climatic responsive design such as efficient air ventilation, to improve thermal comfort in the new Egyptian cites.

A. Natural Ventilation Strategies for Achieving Thermal Comfort

Medhat (2011) investigated the possibility of enhancing the use of natural ventilation as a passive cooling strategy in public housing blocks in the Egyptian desert [climatic region] by using FloVent Computational Fluid Dynamics [CFD] software. He evaluated New Al-Minya city and the effect of different design measures that could possibly enhance natural ventilation performance [8]. Riyadh (2006) verified and examined climatic conditions in the residential areas of Egyptian cities –New Assiut city– by studying the climate impact as well as environmental factors affecting the communities in desert areas. He made field measurements of the indoor climate of the houses, pedestrian pathways between buildings and streets around these buildings in the summer and cold periods in order to take climatic conditions into account when designing new building. He concluded that rooms with northwest and west orientation reach the highest temperature every day, unlike rooms with southeast and east orientation. Also, in case of comparison between inner and outer temperature, the inner temperature exceed the outer temperature by different 7°C especially at night. This indicates that the materials are not suitable for hot climates [14]. Ayman (2000) studied the optimization through performing parametric analysis of one of the youth project prototypes in El-Obour city, located in the desert to the east of Cairo by using DEROB1 computer thermal simulation software. Also, he quantified the effectiveness of different building materials, wall thicknesses, solar shading devices and night purge ventilation during the summer. He found that the quality of airflow circulation within the building spaces and around the human body seems to be more important in cooling down the building fabric and human body than the volume of air induced inside the space [12]. Gado and Osman (2009) studied the effectiveness of natural ventilation strategies used in government dwellings in one of the Egyptian desert climatic design region. Three government housing blocks, built in New Al-Minya city, were employed as case studies. Autodesk-Ecotect and FloVent CFD software were used to simulate the internal air movement and air temperatures. In particular, night purge ventilation was not effective as a passive cooling strategy due to poor air circulation across the dwelling. As a result, taking the advantage of passive cooling would improve the design [13]. Wael and Steve (2010) investigated the thermal behavior of new Cairo housing to enable appropriate solutions to be chosen at the early stages of design and achieve low energy thermal comfort in dwellings. They used DesignBuilder as a satisfactory simulation package which performs sustainability analysis and thermal assessment for dwelling in the New Cairo communities and helps to achieve low energy thermal comfort for domestic buildings in hot climates [15]. Bakr and Mark (2010) used a system to capture prevailing winds from the façade to achieve cross ventilation in a habitable room. The wind ceiling system was tested using CFD simulations and verified in a full scale test; high rates of air change are delivered in several wind directions and speeds. This is believed to reduce the energy consumption due to excessive usage of air conditioning systems, fans and mechanical ventilation systems in high-rise residential buildings in hot humid areas[18]. Other studies use similar parametric analysis to achieve thermal comfort; S. M. Robaa (2003) investigated thermal comfort in Egypt based on a meteorological database [19]. Ibrahim (2006) discussed the integration of the value of eco buildings within the design process based on assessing criteria in Egypt [20].

B. Solar Chimney Strategies for Achieving Thermal Comfort

Egypt in general has rich sunny and clear skies. Some previous studies investigated the use of the solar chimney concept for improving room natural ventilation, which allows amount of solar energy to be stored in a surface, then releases this energy to an adjacent column of air that raises as the temperature increases, and accordingly flows upward drawing fresh outdoor air into the space. Ramadan and Nader (2008) studied some geometrical parameters such as chimney inlet size and width that have significant effect on space ventilation. Numerical analysis was used to intend to predict the flow pattern in the room as well as in the chimney. It can be concluded that increasing the inlet size three times only improved the ACH by almost 11%. However, increasing the chimney width by a factor of three improved the ACH by almost 25%, keeping the inlet size fixed [21].

C. Different Solutions for Achieving Thermal Comfort

Another study by Hassan et al. (2007) looked at the effects of opening locations and sizes [window-to-wall ratio] and building orientation relative to prevailing wind direction, CFD (ANSYS FLOTRAN) was applied to the present problem. Both techniques [visualization and computation] gave clear pictures of what happen inside the ventilated space under different opening locations and combinations for various wind directions [22]. Gado (2000) studied the possibility of formulating effective passive design strategies and measures that could be used in different climatic design regions of Egypt to enhance the thermal comfort and energy efficiency. One of the youth housing project prototypes was used as a case study. A parametric analysis was conducted using Autodesk Ecotect1 and HTB22 software in order to quantify the effectiveness of the proposed passive measures in terms of thermal comfort and energy efficiency. This work concluded that the use of insulated external walls with light external colours along with extensive shading devices in a tight building is the best combination of passive measures that may work across all the Egyptian climatic design regions [23]. Abdin (1982) studied a comprehensive bio-climatic approach for housing design in semi deserts and hot climates within Egypt, which focused on natural ventilation and airflow patterns in and around buildings. Four public housing prototypes built in Cairo were employed as case studies. A wind tunnel aerodynamics tool was used to test the effect of several design factors on airflow regime and around the physical models of the case study buildings. He developed a list of guidelines for ventilation optimization for comprehensive bio-climatic approach [24].

As a result, it could be argued that the majority of past studied dealing with achieving thermal comfort through applying several measures. Most of them recommended the use of different ventilation and passive cooling strategies. But the problem of achieving thermal comfort inside new Egyptian housing need to be studied and new strategies need to be developed.

IV. Research on New Strategies and New Evaluation System for Thermal Comfort

After considering past research and strategies, most of them recommended the use of ventilation strategies, especially natural ventilation and solar chimney that can be effectively used for cooling purposes and reduce the heat gain. Nowadays, there are many new strategies and passive systems that help in achieving thermal comfort inside new buildings and adapt the old concepts of the traditional buildings to achieve comfort with low energy consumption.

A study in Spain with similar conditions presented a practical approach to improve the passive night ventilation in public social housing by applying the solar chimney concept. Macias et al. (2006) used an accessible high thermal mass in building construction to collect solar energy during the afternoon in their concrete walls [50°C]. For every flat there was a separate chimney with a swinging flap at top, and while collecting energy the flap was closed. Then, during night when the ambient temperature drops to about 20°C the flaps at the top were opened generating a draft through flats, cooling down the thermal masses of the ceiling and walls [25]. Another study in Thailand, Chungloo and Limmeechokchai (2007) addressed the effect of solar chimneys and/or water spraying on a roof on natural ventilation. When the ambient temperature was 40°C, they achieved a maximum of 3.5°C reduction in temperature for the case of separate chimney, and a maximum of 6.2°C reduction in temperature for the combined effect of charging a solar chimney and spraying water. Also, they reported that the temperature difference between the inlet and outlet of the solar chimney tends to decrease during the period of high solar radiation and high ambient temperature. As a result, spraying water increases the temperature difference and consequently the air flow rate through the chimney [26]. Several studies research the integration of different strategies to decrease the limitations and disadvantages of a single strategy to increase thermal comfort. Bansal et al. (1994) investigated a wind tower coupled with a solar chimney design. The system consisted of a uniform cross sectioned wind tower which connects to the rooms to catch natural ventilation. Solar chimneys were used to enhance stack effects for exhausts at purposefully designed exits. The overall flow of air is a combined effect of aeromotive and thermal forces. In a wind tower, thermal forces are negligible, whereas in a solar chimney, the dominant air flow is created by thermal buoyancy. Such a system provides ventilation for variable wind speeds with a collector area of 3.0 m^2 [27].

Another study Maerefat and Haghighi (2010) puts forward a new solar system employing a solar chimney together with an evaporative cooling cavity. The numerical experiments showed that this integrated system with proper configuration was capable of providing good indoor conditions during the day in a living room even at a poor solar intensity of 200W/m^2 and high ambient air temperature of 40°C. Although the performance strongly depended on the ambient air humidity it was easy to create good indoor thermal conditions when the ambient air's relative humidity is lower than 50% even at high ambient temperatures. Also, when the ambient air temperature become 34°C at 1000W/m^2 and the relative humidity 40%, the resulting indoor temperature decreases to 26.26°C with relative humidity 85.57%. It was suggested that a combination of the proposed system would help to create a reasonable indoor environment for human thermal comfort as well as to be energy efficient and environmentally friendly [28].

V. Conclusions

It is important and urgent to increase our knowledge about present problem concerning indoor climate and thermal performance in today's building stock. From the above review of the available work done in Egypt, it could be argued that the majority of work dealt with achieving thermal comfort through applying several passive cooling strategies. Most of them recommended the use of ventilation strategies, especially natural ventilation, cross ventilation, the window-to-wall ratio and building orientation relative to prevailing winds direction and solar chimneys to reduce the heat gain. Very few researchers discuss integration strategies using natural ventilation with evaporating cooling strategy to achieve thermal comfort and low energy consumption for cooling purpose.

From research on new strategies it was concluded that solar chimney technology is a very suitable system for regions where solar radiation is high especially Egypt. solar chimneys can be used to reduce the accumulated heat of the house continuously. Warda et al. (2010) concluded that using roof solar chimney with vertical stack, the temperature difference reached 9.9°C in semi clear sky condition at 877 w/m^2 [29]. But in order to achieve a desired natural cooling effect, it is interesting to combine the solar chimneys with natural cooling systems including evaporative cooling and/or wind tower with natural cooling systems. Sudaporn et al. (2007) concluded that solar chimney achieve 3.5°C reduction in temperature when using separate chimney and 6.2°C reduction when using solar chimney and water effect [26]. Also, With integration of wind catcher and passive evaporating strategies to achieve indoor thermal comfort. Yasmina et al. (2011) concluded that the difference between indoor and outdoor temperature decrease by 15°C and relative humidity increase by 62% [30]. Bahadoria et al. (2008) concluded that indoor temperature decrease by 24.1°C and relative humidity increase by 48.5% [31]. Therefore, more experiments are still needed to be done so as to testify the performance of the integrated systems. Besides, it seems necessary to carry out further researches including both the optimization and control strategy of such integrated systems in different climates especially in Egyptian housing to provide cooling effect inside Egyptian housing with low energy consumption.

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