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DESIGNING SUSTAINABILITY FOR ALL

Edited by Marcelo Ambrosio and Carlo Vezzoli

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SUSTAINABLE TECHNIQUES TO IMPROVE THE INDOOR AIR QUALITY (IAQ) AND THERMAL COMFORT IN HOT AND ARID CLIMATE.

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ABSTRACT

Nowadays an increasing number of people spend a lot of their time in indoor spaces and the global market for Heating, Ventilation and Air Conditioning (HVAC) is increasing very quickly to improve the indoor air quality and the thermal comfort. The International Energy Agency assesses that almost the 20% of global energy consumption is addressed to mechanical air conditioning. The use of local resources and the rediscovery opportunities given by passive cooing and ventilation systems may suggest interesting ways to provide benefits for humans and to reduce environmental footprint. The paper focuses on the application of wind-catcher system in a modern public school in the city of Yazd (Iran), in a hot and arid climate zone. Opportunities and benefits are discussed to evaluate the efficiency of the redesign of the traditional wind-catcher and its integration in new modern buildings.

Key Words: Natural ventilation, Cultural identity, Climate adaptation, Low-carbon solution.

1. INTRODUCTION

In recent years, an increasing number of people around the world spend about 90% of their time in indoor spaces (Liu et al., 2019) such as school, work place, home and other public spaces. The attention addressed to the improvement of indoor environmental comfort and to indoor air quality (IAQ) is increasing in new building design strategy. In the WHO's report (2000), the Woking Group established that all organizations, public and private, must ensure adequate air quality for their occupants (Principle 4), because everyone has the right to breathe healthy indoor air and to live in healthy environments. The high level of indoor chemical pollutants, such as carbon dioxide (CO_2), nitrogen dioxide (NO_2), formaldehyde, benzene and other volatile organic compounds (VOCs), can contribute to causing the Sick Building Syndrome (SBS) in occupants. These chemical pollutants are present, in different concentration, in all indoor environments, because they are released by furniture, paints, cleaning products, computers and photocopiers (Yanpeng et al., 2018). The SBS is healthy condition that occurs with headache, fatigue, irritation of eyes, nose and throat, problems in focus and dry/itchy skin.

These health problems can adversely affect working and learning skills, especially in young people and children (Kishi et al., 2018), because they often spend a lot of their time in schools, libraries and study halls and they are particularly sensitive to chemical and microbiological pollutants. Another important aspect for the welfare of occupants and their productivity in public spaces regards the thermal comfort. Existing building code, such as ASHRAE Standards and the ISO Regulations, require a minimum ventilation rates, but very often it doesn't satisfy people's requests. The research published by Nnduka et al. (2018) asserts that the quality of ventilation and cleaning mostly affect the perception of human comfort in indoor spaces than other factors. In new buildings mechanized and automatic systems are used to provide high performances to improve the indoor environmental quality (IEQ). Nowadays the global demand for Heating, Ventilation and Air Conditioning (HVAC) is strongly increasing and many studies assert that buildings are responsible for 40% of global energy consumption for operation and control and more than 30% of worldwide carbon emission (Liu et al., 2019).

These numbers might increase in the future and the increase of energy consumption might affect the integrity and the quality of built environment. Green policies promote the reduction of the environmental impact of HVAC, without neglecting well-being and work productivity of occupants. In many cases, the problem can be solved by providing proper passive systems of ventilation, that contributes to ensure the provision of air quality and quantity, to reduce energy costs for building management and also to decrease the ecological footprint. This paper focus on the investigation of benefits of natural ventilation strategy and its application in the design of a public school in the city of Yazd (Iran), characterized by hot and arid climate. In the framework of sustainability, the study of the context is essential to analyse local resources and to design an efficient low-energy-carbon ventilation system. In conclusion, the paper highlights the importance of connections between natural ventilation, thermal comfort and healthy indoor environment through the rediscovery of traditional architectural techniques, applied in a new building, for the provision of fresh air in indoor spaces.

2. DESIGN FOR SUSTAINABLE LIVING: SUSTAINABILITY AS DRIVER IN DESIGN PRACTICE

The concept of sustainability is a key issue in many fields of our society. The UN Sustainable Development Goals (SDGs), especially the SDG 11, remark that the main global challenge is to provide high quality standards of living spaces for a large population, without damaging natural ecosystems. In the design practice of indoor spaces, sustainability assumes a humanistic dimension, that focuses on human wellbeing, and an environmental dimension, that concerns energy reduction for building control. Another important aspect to deal with sustainability in architecture is the relationship between the design practice and the territory.

Local geography, cultural identity and especially the bond between man and nature have played a crucial role in defining main features of traditional Iranian architecture (Khaki et al., 2015). One of the challenges in contemporary architecture is to understand if the traditional holistic attitude can respond to the optimization of energy consumption and to the provision of satisfying comfort. Looking at the seven principles of sustainability in Iranian traditional architecture (Khaki et al. 2015), the use of renewable energy, the reduction of use of raw materials and the design in coordination with the local geography are considered as main drivers in designing solutions to satisfy needs of the occupants. In the sustainable view, buildings are considered as parts of wider environmental system, characterized by specific regional and economic conditions, microclimate, culture, material and energy resources. In addition to these, it may be useful to also consider the 4R rules (reduce, recycle, reuse and renewable) in the design process (Li, 2011) to chase sustainability in the management of conditions of indoor spaces that affect the thermal comfort and air quality.0

These principles suggest that traditional Iranian architectural elements have been designed based on available local resources and in order to minimize the environmental impact. The analysis of the regional context investigates all important features of a specific territory, not only geographical and climate characteristics, but also the traditional know-how, the material culture and history. This analysis is the first important step in the research methodology to identify local opportunities in order to ensure environmental resilience and sustainable development.

3. REGIONAL FRAMEWORK AND CLIMATE ADAPTATION BY DESIGN

3.1. Geographic and climate framework

Iran is the second largest country in the Middle East it is located between the Persian Gulf and the Oman Sea in the south, and the Caspian Sea in the North. From the North to the South the country presents three climate areas: the desert with hot-arid climate, semi-arid climate in the wider part of Iran and Mediterranean. Yazd city is located in the desert region in the middle of Iran. Yazd province has a very typical climate conditions that presents cold winters and very hot and long summers. Low precipitation (60 mm in a year) and humidity (between 12% and 16%), shortage of water, high season temperature range (40°C in summer and -8°C in winter), dusty and sandy winds and scarcity of vegetation covering are perceived as limitations for planners and residents (Etminen, Ilkhanlar, 2017). On the other hand, the high amount of wind and solar radiation are considered as valid resources for the development of new opportunities for the transition of the use of fossil fuels to renewable energies. Iran is considered as one of richest country all over the world for alternative energy resources. In particular, in the Yazd province there is the perfect condition for the development of diffuse wind farms. The city of Yazd is located in a natural wind tunnel with almost permanent wind flow that provides suitable conditions for harnessing the wind energy.

3.2. Traditional elements for climate-adaptive architecture

Looking at the contemporary urban planning of Yazd, it appears inadequate for the local climatic features and the design of buildings fails to meet environmentally friendly requirements. The fast growth of Yazd to accommodate rural mitigation, as the result of the Reza Shah's land reforms in 1960, has created a strong demand for housing. Cheap and quick construction buildings were adopted as the best solution by the government. In modern buildings the importance of traditional architectonic elements was strongly decreased, and the main result is the inadequate provision of quality standards regard comfort and liveability. In the past, people have always been affected by harsh climate and this has led them to finding solutions to make the weather condition more tolerable and less annoying (Dalvand et al. 2015). Ancient buildings, houses and streets was designed considering range of temperature, speed and frequency of wind, number of hours of sunshine per day, precipitation and relative humidity (RH). Climate-adaptive architecture is usually based on the worst climate conditions of the year, available resources and constraints. On the other hand, many opportunities should be taken into consideration to mitigate harsh climate conditions, such as the use of underground water canals (Qanats), the increase of humidity, shading and ventilation using wind tower system and planting trees and bushes in courtyard.

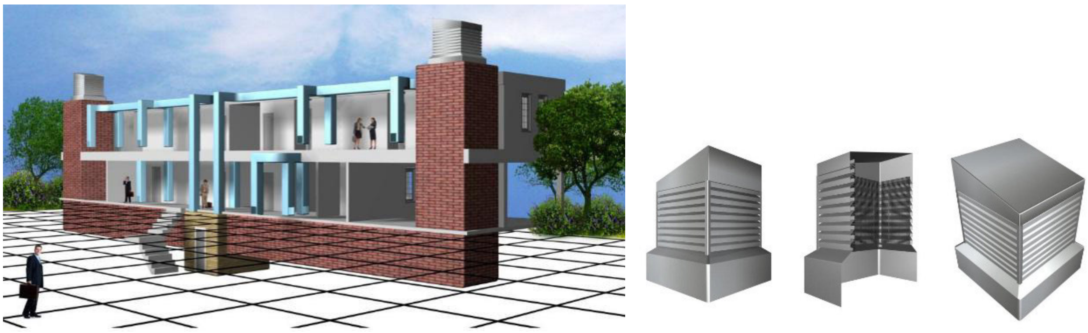
Following principles of design for sustainability (Khaki et al. 2015), natural resources should be used in architecture to provide comfort and benefits for occupants. The vernacular architecture is strongly influenced by nature to comply with the geographical and climatic features. Traditional elements should be combined with high-tech solutions to decrease the environmental impact while increasing the thermal comfort and the IAQ. The air circulation, through passive cooling and natural ventilation, is a central aspect in vernacular architecture of Yazd, at the level of single building, of neighbourhood and of city. Courtyards, vegetation, internal pools and underground canals for water and windcatchers contribute to provide high quality standards for indoor spaces. Windcatchers are ancient passive cooling and ventilation systems hailing from the Persian Gulf area, Pakistan and North Africa region. The air flow occurs either due to the wind blowing or the temperature difference between the interior and the exterior of the building. When the wind blows, it is captured by the chimney and flows downwards cooling itself and it is distributed in the rooms, while the warm air flows upwards. In windless conditions, the wind-catchers operate like an air trap according to the stack effect: hot and less dense air rises and outflows from the wind-catcher's openings (Ahmadikia et al. 2012).

3.3. The use of windcatchers in contemporary architecture

In many cases architects and engineers integrate the principles of traditional windcatchers with contemporary technology as helpful devices to increase the quality and the efficiency of the supplied air. Modern windcatchers are usually more compact and smaller than traditional ones. In these modern systems, air is supplied to indoor spaces through diffusers located at the ceiling level, allowing for more space for ventilation. From Eastern to Western countries, there are many application of windcatchers technology in modern public buildings, such as the Sohrabji Godrej green business center in Hyderabad (Andra Pradesh, India), the Zion national park visitor center in Utah (USA), the Lanchester library in Coventry (UK), the UCL school of Slavonic and Eastern European studies in London (UK) and the Bluewater shopping mall in Kent (UK). In these building windcatchers contribute to the provision of natural ventilation, lighting and fresh indoor air.

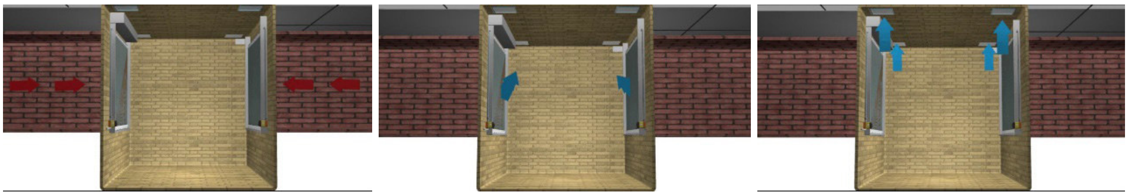
4. THE APPLICATION OF SUSTAINABLE PRINCIPLE IN NEW SCHOOL BUILDING IN YAZD

The goal of this study is to design a new school building in Yazd, following the principles of sustainability, in order to reduce the energy consumption for its operational control. The area under study is located in the new urban fabric in the North-West of Yazd, a rapidly expanding area. The focus is addressed on natural ventilation as a valid choice for air conditioning, thermal comfort and air flows. Natural ventilation provides also many secondary benefits for the well-being of the occupants, such as the disposal of fan noise linked to mechanical systems and the cost effective for the maintenance. Classrooms, dining halls, libraries and gymnasiums are spaces where natural ventilation is vital for the well-being of the occupants. Wind-catcher system is also appropriate for transition spaces without windows, such as corridors and store rooms. The application here presented is designed for a primary school with a maximum capacity of 140 students, divided into 10 classes on two floors. However, the ventilation system is designed to be applied in different type of buildings in the same climate zone. The school is equipped with two air supplier canals and six exhaust air ducts (wind-catchers). On the top of two chimney there are special wind rotation caps equipped with wind lead sheets to rotate in the direction of the wind. Functions of these caps are to better catch the external air, to reduce the amount of dust and suspended particles, which are being channeled into the canals, and to protect canals against rain water (Figure 1). The two main canals of the wind-catcher are linked with the air division room (or technical room), placed at the basement of the building, where the incoming air is divided between the other ducts that terminate into classes.



[Figure 1] Section of building that shows the two main canals and the air ducts and details of wind-catchers structure.

Canals of the wind-catchers and of the basement are made by adobe material capable of absorbing humidity. In order to increase the absorption of humidity, the internal surfaces of wind-catchers canals are made of adobe. The cooling effect is more efficient by spraying the pads of air division room with water, a technique frequently used in cooling towers, humidifiers and evaporative coolers. Firstly, warm air (almost 40°C and 10% of RH) is drawn inside through a porous wet pad and the water contained into the material absorbs heat and evaporates from the pad. At the end, the air leaves the systems at lower temperature of 22°C and 50% of RH and it exits by four opening on the ceiling to enter into air ducts to be distributed in indoor spaces (Figure 2).

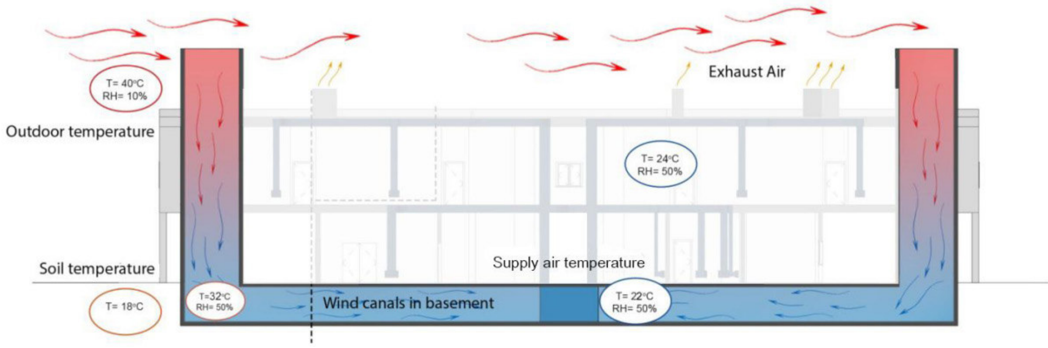


[Figure 2] Air flow through the windows composed by three cellulose pads in the technical room placed at the basement of the building.

The efficiency of evaporative pad system is affected by the surface area and thickness of pads, the type of material, the size of perforations, the flow rate and humidity of incoming air and the volume of water used. Considering locally available cheap materials and previous studies (Hou, 2016), cellulose pads, recently designed for evaporative cooling for industrial and residential sectors, are chosen as the best solution for this application. These pads have high ability in absorbing water, and they are chemically treated to prevent disintegration. The technical room is provided with two windows for the inlet of air from wind-catchers canals, which are made by three cellulose pads for each window. Windows are also equipped with automated water supplier for spraying water on cellulose pads and with an automatic door to close the ventilation system in winter season.

5. CONCLUSIONS AND REMARKS

According to meteorological data collected regard temperature (maximum around 38°C in the daytime) and relative humidity (between 12% and 16%) in Yazd during the summer, these parameters are beyond the comfort zone. In the transition period between April and October, Yazd is the comfort zone, but in the other months of the year it is necessary to provide more comfortable indoor temperature and moisture (Soleymanpour et al. 2015). The case study illustrates very simple but effective moisturizing in order to increase the evaporation process and also moisturize the dry air in winter. In the natural cooling process the air flows through the adobe wind canals in the basement. During summer the underground temperature in Yazd is between 16°C and 24°C and the air gets cooler passing through underground canals and wet cellulose pads. Natural ventilation contributes to improve the thermal comfort and the IAQ, using natural resources and reducing the energy consumption. The case study presents the application of an hybrid strategy of vernacular and modern systems to improve levels of standards of comfort and sustainability in new public buildings. The analysis of the efficiency of the cooling and ventilation system shows that in the hottest days in Yazd (40°C and 10% of RH) the air could be cooled down up to 24°C and 50% of RH (Figure 3). The rediscovery of traditional architectural elements can be useful to improve the sustainable liveability of modern buildings and also to preserve the cultural identity and the traditional know-how of the Yazd territory.



[Figure 3] Temperature course diagram and air flow scheme in the natural cooling system in the school in a hot summer day.

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