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A review of passive envelope measures for improved building energy efficiency in the UAE

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A R T I C L E I N F O

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A B S T R A C T

The United Arab Emirates' (UAE) hot climate, coupled with the extreme demographic and urban growth experienced over the past four decades, has shaped a built environment where energetic quality of construction has been superseded by the quantity of construction needed to support the country's growth. This development is further aggravated by the slow development of energetic building codes, as well as the subsidized cost of electricity. The result is that the UAE consistently leads the list of countries with the highest environmental footprint, and the electricity production required to drive building cooling constitutes the brunt of the emissions balance-sheet. The work presented here reviews primarily UAE-based research that addresses the effectiveness of passive building-envelope measures that reduce energy consumption. A number of measures have been developed in response to the increasing demands of emerging energy regulations, and include measures specific to the building envelope in the planning phase or as retrofit, including radiative, convective and conductive heat transfer through walls, windows, roof, as well as energy efficient natural ventilation techniques. This review is geographically restricted to the UAE as its development challenges are directly tied to its distinct economic growth pattern and specific legislation implemented to address energy efficiency. Results confirm the importance of the following factors for energy-optimized structures: building orientation, thermal insulation (which can generate in excess of 20% energy savings in particular in the residential context), appropriate glazing type and orientation in highly glazed office buildings (up to 55% energy savings reported), excessive light levels and glare, and natural ventilation, which can reduce energy consumption from a reported high of 30% in villas to up to 79% in a high rise office building using mixed mode ventilation.

1. Introduction

The worldwide building sector consumed 32% of the global final energy in 2010, and was responsible for one-third of global CO_2 emissions [1]. Building energy consumption is particularly pronounced in extreme climates, where indoor space conditioning constitutes the largest portion of a building's energy needs. In both cold and hot climates, active systems have to either heat or cool the building to maintain occupant comfort. Further, humidity levels must be kept at acceptable levels, and sufficient fresh air has to be delivered to ensure a healthy environment for occupants. Thus a building's energy consumption is governed by climatological factors, technical factors (energetic quality of the building's envelope and space conditioning), and occupant behavior [2].

In cold climates most energy is consumed by on-site burning of biomass and fossil fuels to generate heat, while in hot climates the space conditioning systems typically rely on electricity as energy source. Energy efficiency strategies however are similar, as heat is lost or gained through the building envelope. Conduction losses through the wall and windows are mitigated in both cases by decreasing the enclosure's U value. Radiative losses or gains however receive a different treatment, as in cold climates they are desirable to reduce heating load, whereas in hot climates they increase the cooling load. Thus in climates like the UAE, window treatments in the form of selective coatings and the appropriate design of shading elements become critical fenestration components. In both cases, and in order to minimize energy consumption, it is important to first optimize the envelope and then address the active heating or cooling systems, as

Abbreviations: HVAC, Heating, Ventilation and Air Conditioning; GDP, Gross Domestic Product; DPW, Department of Public Works; USGBC, US Green Building Council; LEED, Leadership in Energy and Environmental Design; U-value, Heat transmittance through a building component (W/m^2 K); EPS, Expanded Polystyrene; AAC, Autoclaved Aerated Concrete; EUI, Energy Utilization Intensity (kWh/m^2 a); SHGC, Solar Heat Gain Coefficient; GHG, Greenhouse Gas; CAV, Constant Air Volume; VAV, Variable Air Volume

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Fig. 1. Typical single-family villa development in Dubai.

these can consequently be sized for a smaller load.

On the long term, and taking into consideration climate change, worldwide heating energy demand is projected to decrease by 34% by the year 2100, while cooling demand is estimated to increase by 72% over the same time period [3]. Thus the already severe cooling need of buildings in arid regions is projected to increase over the next century, further impacting the often poor energetic and sustainability balance sheet of these regions, and underscoring the necessity of energy efficiency measures.

The UAE's extreme climate generates a challenging environment for energy conservation and environmental sustainability of buildings [4]. The temperature (wet bulb design temperature of 30.6 °C and dry bulb design temperature of 45.0 °C [5]) and humidity (80% in winter and 70% in summer [5]), combined with the high solar irradiance (yearly average global horizontal irradiance in excess of 20 MJ/m^2/day [6]), make air conditioning a necessity to maintain acceptable indoor comfort levels. The resulting electric load attributable to HVAC equipment accounts for 40% of the total year average electrical load, and up to 60% of the summer peak load [7].

The challenges that arise due to these extreme climatic conditions are further compounded by the exponential growth of the country since its formation as a federation of seven Emirates in 1971. The UAE's Gross Domestic Product (GDP) has risen at an average rate of 4.9% annually from 30 Billion $US in 1980 to 81 Billion $US in 2003, and the resulting population growth spans from an estimated 0.7 million inhabitants in 1980, to 3.25 million in 2003 to 9.157 million in 2015 [8,9]. This rapid growth, primarily caused by the economic development due to oil sales and the ongoing repositioning of the country as a commerce and high-tech hub, has triggered a continuous influx of foreign workers and businesses. The infrastructure and urban development to support this growth has had to assume unprecedented scale.

Looking at the example of the Emirate of Dubai, first available statistics from 1955 show an urban area of only 3.2 km^2 in 1955, which grew to 606 km^2 in 2004, with further plans to extend the built-up area by another 501 km^2 by 2015 [10]. The urban development has adopted a cluster approach, with numerous mixed-use and residential clusters. In addition to housing developed for UAE nationals provided by the Department of Public Works (DPW), the clusters are typically developed by one of the major real estate developers, and sold as investment property or for personal use. Bagaeen [11] argues that the opening of the real estate market to the exterior, by allowing foreigners to buy freehold property in Dubai, has been the catalyst of this rampant expansion. In order to maximize profits, the major developers pursue economies of scale, and it is not uncommon to have hundreds (if not thousands) of homes built simultaneously in newly developed areas (Fig. 1). In accordance, the residential villa stock has grown by over 300% from 2000 until 2009 [12].

The growth in energy demand follows suit: in 1995 the demand was 25 TWh, in 2003 50 TWh, and in 2007 76 TWh [7], of which (2005 data) 45.9% was attributable to residential buildings and only 2.5% to commercial buildings [13]. Mokri et al. [6] report an annual increase in electricity demand of 10.8%.

A key factor contributing to this very high energy demand growth rate is that the cost of energy is kept artificially low through government subsidies. While the cost of production of a kWh of electricity is estimated to be $0.12 to $0.13, it is sold at an average rate of $0.04 per kWh in Abu Dhabi (with a further reduction for UAE nationals), and at a slab rate ranging from $0.06 to $ 0.10 per kWh in Dubai [5]. In addition to these low prices (and notwithstanding increasing efforts by the government to counteract this), there is a general unawareness of environmental and energetic considerations in the population [8]. These factors contribute to an average per-capita energy consumption that is nine times higher than the world's average energy consumption, four times higher than the EU's energy consumption, and two times higher than the US energy consumption [8]. These factors make the UAE the country with the highest ecological footprint in the world [5].

Thus an environment inclined to poor energy efficiency is created by:

- The need for rapid construction to accommodate rapid population growth
- The large-developer business model, where profit is maximized while keeping initial construction costs low [14]
- The artificially low cost of energy, reducing the perceived importance of operational cooling costs during the lifetime of the building
- The long time absence of any energy regulation forcing the implementation of insulation and efficiency measures
- The general unawareness of environmental concerns by the population

The UAE government is actively pursuing renewable energy technologies with the aim of addressing worldwide concerns regarding global warming and greenhouse gas emissions, and at the same time preparing an economic pillar for the country's growth beyond the oil years [6]. However, while renewable production has received much attention, energy conservation through effective construction is only slowly becoming mainstream through the development and implementation of adequate legislation.

This paper provides a review of work done specifically in the UAE on improving building energy efficiency by passive measures implemented to the building envelope in the planning phase or as retrofit, including radiative, convective and conductive heat transfer through walls, windows, roof, as well as energy efficient natural ventilation techniques. The review is geographically restricted to the UAE as its specific development challenges are directly tied to the distinct economic growth pattern of the country and the specific legislation