Optimised passive design for Commercial building in Arid Climate – Energy Efficiency

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***Abstract*—Cooling demands of commercial buildings present a relevant challenge for a sustainable future. It is widely agreed that the application of passive design strategies should be the first step in the design of energy efficient buildings and then the design of active systems shall be done to avoid over sizing of the equipment installed. In this paper, a systematic review of previous studies along with the implementation of passive design strategies to an existing commercial building in the State of Qatar is performed to investigate the effectiveness of the implementation of these strategies on the overall energy consumption of the building and its impact on the associated carbon emissions. In total, 7 different strategies were identified and the effect of each of the strategies on energy consumption was calculated using an Energy Simulation Tool. This paper explores the effectiveness of the passive design strategies in commercial buildings in hot and arid climate and the percentage change in the energy consumption and associated carbon emissions. The general findings showed that implementing effective passive design strategies could lead to reduction of energy consumption and reduction in carbon emissions by upto 34%.**

***Index Terms*—Passive Strategies, energy efficiency, energy savings, Hot and Arid Climate, Commercial Buildings in Gulf Cooperation Council (GCC)**

I. Introduction

1.1 Background

Cooling demands of commercial buildings in Arid Climate presents a relevant challenge for a sustainable future and energy conservation. Energy demand for cooling these buildings can account for more than half of the total energy consumption owing to the elevated temperatures and with the increase in temperatures worldwide, this demand is deemed to increase further.

This dissertation aims to investigate the effect of passive design strategies on the energy consumption of buildings. As the world grapples with the challenges of climate change and the need for sustainable development, understanding the role of passive design in reducing energy consumption becomes crucial. Implementing passive design strategies in buildings can greatly reduce energy consumption. This not only helps in reducing operational costs but also contributes to environmental sustainability by minimizing greenhouse gas emissions and reducing reliance on non-renewable energy sources.

The research will explore various passive design elements, such as orientation, insulation, ventilation, and shading, and their collective impact on a building's overall energy performance.

Various databases such as ScienceDirect, Google Scholar and Elsevier were used to select the initial publications with the following search terms and words:

- Passive strategies, passive cooling, Energy Efficiency, Energy Savings, Commercial buildings, Hot and Humid temperatures
- Building: Commercial buildings
- Location: Gulf Cooperation Council (GCC)

The publications included were selected based on the studies addressing the effect of passive design and strategies on energy consumption for commercial buildings in hot and arid climate such as Qatar or Gulf Cooperation Council (GCC) in general.

1.2 Climate Change and Energy Efficiency

Human-caused interventions have been identified as the highest contributor of greenhouse gases (GHG) emissions, which are directly linked to the causes of global warming (IPCC, 2015; (Jentsch et al., 2008)). This rise in temperature has also been the most critical reason for the change in climatic conditions clear over the earlier few decades.
Considering that the buildings are one of the most energy consuming constructions, there is also an extremely high potential for increasing the energy efficiency of the buildings and thereby reducing the amount of GHG emissions and controlling the global warming.
As per an IEA report, residential and commercial buildings account for approximately 47% of the total energy consumption of the world. Operational energy use in buildings represents about 30% of global final energy consumption. This share jumps to 34% when including the final energy use associated with the production of cement, steel, and aluminium for the construction of buildings.
In 2022, for the second year in a row, space cooling saw the largest increase in demand across all buildings end uses, up by more than 3% compared to 2021. By contrast, space heating energy consumption decreased by 4%, mainly driven by a mild winter in several regions, including Europe.
During the past decade, energy demand in buildings has seen an average annual growth of just over 1%. In 2022 energy demand in buildings increased by nearly 1% compared with 2021. Electricity accounted for about 35% of buildings' energy use in 2022, up from 30% in 2010. Despite a progressive shift from fossil fuels to other energy sources and vectors – especially electricity and renewables – fossil fuel use in buildings has increased at an average annual growth rate of 0.5% since 2010.
Therefore, it becomes clear that the primary concern of the building designer should be to design a building in such a way that reduces the overall energy demand of the building. This lower energy demand will further result in lower equipment capacity installation and thereby reducing the need for energy.

II. AIM AND OBJECTIVES

2.1 Aim

The primary aim of this research is to investigate the impact of passive design strategies on the overall energy consumption of a commercial building and to create a new passive design on an existing building that can be used as a model for future construction projects.

2.2 Objectives

The above aim shall be carried out by means of achieving the below objectives:

1. Investigate the effect of passive design on the energy consumption of buildings as documented in the literature.
2. Examine the existing state of the selected building considering energy consumption.
3. Identify key passive design strategies that improve energy performance.
4. Assess the economic and environmental implications before and after adopting the newly developed passive design.

III. LITERATURE REVIEW

3.1 Passive Design Strategies

Passive design' is design that works with the local climate to support a comfortable temperature in the space. Good passive design should reduce or drop the need for additional heating or cooling depending on your location and often relies on an active occupant to work properly. A passively designed space can ensure effective thermal comfort, lower energy consumption, and lower greenhouse gas emissions.

The passive design of the building makes use of the building features such as thermal mass, orientation, insulation and glazing to ensure that the heat gain or loss is minimum, and the cooling or heating demand of the building is optimised.

Passive cooling is commonly understood as a set of natural processes and techniques to reduce indoor temperatures, in opposition to the use of 'active' mechanical equipment. Nonetheless, this binary distinction present problems in practice, addressed by several authors when stating that the use of minor mechanical equipment such as fans and pumps is allowed under the term 'passive' if their application might result in a better performance (Givoni, 1994). Therefore, it is possible to find two distinct groups within passive cooling concepts, based on the use of auxiliary equipment.

On the one hand, strategies such as solar control, building layout, orientation, and control of internal heat sources, are presented in the literature as 'bioclimatic design strategies' (Givoni, 1994), 'basic building design' (Lechner, 20189) , or simply 'passive cooling' (Santamouris and Santamouris, n.d.) . On the other hand, concepts which benefit by the use of pumps or fans, such as geothermal, evaporative and radiative cooling or night flush ventilation, are defined as 'natural cooling' (Santamouris and Santamouris, n.d.) or most commonly 'passive cooling systems' (Lechner, 20189),(Givoni, 1994),(Hepbasli, 2012) . Nevertheless, the common attribute of all mentioned strategies is that they are driven by low valued energy, in the form of environmental heat sources and sinks (low-exergy in- stead of high-exergy sources such as electricity) (Hepbasli, 2012),(Energy Conservation in Buildings and Community Systems Programme, 2004) . Thus, an extra layer in the discussion was added by Kalz and Pfafferott by categorizing the discussed groups in 'passive low-ex' and 'active low-ex' cooling systems, in a declared effort to propose less ambiguous terminology (Kalz and Pfafferott, n.d.) .

From a physics standpoint, cooling strategies are also categorized in the literature according to the way they handle heat, basically distinguishing heat avoidance/protection, heat modulation, and heat dissipation principles and according to strategies [(Santamouris and Santamouris, n.d.),(Geetha and Velraj, 2012)]. he fact that heat modulation techniques do not reduce cooling loads by themselves has been discussed by some authors, choosing to present them as a complement of heat dissipation/heat rejection cooling strategies [(Lechner, 20189),("Givoni, B. (1994) Passive and Low Energy Cooling of Buildings. John Wiley and Sons, Inc., Toronto. - References - Scientific Research Publishing," n.d.)], storing heat indoors to be released outside at a more convenient time. Hence, basic passive cooling principles seek to primarily avoid unwanted heat, while dissipating the surplus throughout environmental heat sinks.

3.2 Energy Efficiency Regulations and Framework

Due to the rapid growth of the cities, the environment aspect of this urbanisation is ignored for decades which has led to severe weather phenomena's such as floods, draughts, cyclones etc. This extreme change in weather has led countries and other institutions to take notice and impose strict rules and regulations to ensure that the rapid development does not hamper the environment and biodiversity.

Currently, a sustainable act has been witnessed in the Gulf Cooperation Council (CGG) countries: green building councils are being formed, sustainable and energy-efficient structures are being built, and various studies have started to emerge related to energy saving and the potential of sustainable practices in the area (Akbari and Konopacki, 2005); (Awawdeh and Tweed, n.d.); (Hertog and Luciani, 2009); (Meltzer et al., 2014); (Radhi and Barch, 2008); (Willis, 2015)).

However, most of the studies proclaimed energy savings based on a theoretical basis and parametric studies. For the purpose of this paper, only the passive design strategies were focused on as these are the first step towards the energy efficiency of the building as it decides the thermal energy demand of the building based on which the active systems such as equipment size are determined.

This stage is also beneficial since any changes that need to be made are not financially impactful as changes made during the construction stage of the project.

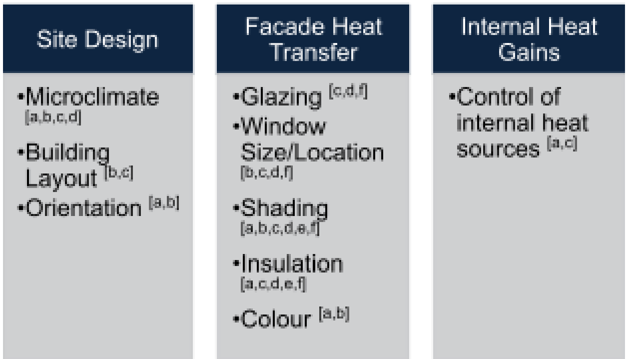
IV. IMPLEMENTATION OF PASSIVE DESIGN STRATEGIES

4.1 Strategy and Methods

The evaluation was conducted in two sequential steps. First, a review of performance results from previous research experiences was carried out, to determine the performance ranges for each cooling strategy considering multiple scenarios.

Following this, an energy simulation software was used to analyse the effect of various passive design parameters on the thermal energy demand of the building. The results of the outcome of the energy simulation software were compared subsequently.

Passive strategies that affect the energy consumption of the building directly are shown in Figure 1.



a. (Lechner, 20189)
b. (Givoni, 1994)
c. (Santamouris and Santamouris, n.d.)
d. (Geetha and Velraj, 2012)
e. (Samuel et al., 2013)
f. (Kalz and Pfafferott, n.d.)

Figure 1: Passive Cooling Design Strategies based on the literature review.

The main focus is on direct passive design strategies as these represent the first step toward energy efficiency. The comparison between the different scenarios is based on the energy utilization index, total yearly energy consumption and the amount of greenhouse gases emitted by implementation of the identified passive design strategies.

4.2 Building Introduction

The building considered in the assessment is a mixed-use commercial building (Figure 2) located in Marina district of Lusail in the State of Qatar with a total plot area of 12, 541 square meters. The building consists of 3 basements, Ground, Mezzanine and 27 floors along with a penthouse. The total built up area for the building is 114, 566 square meters with a height of 100.80 meters. ("Burj Alfardan | AEB," n.d.).

The overall design of the structure portrays a unity of geometric and organic shapes. Opening to the public is a four-storey podium with curved, organic lines and a glazed façade intended for an automobile show

room which smoothly transitions into a soaring, symmetric, sharp edged 32-storey tower designed for retail and commercial use.
The design strives to comply with planning requirements set forth by the Lusail Administration Complex (LAC) to ensure that not only does it provide the required areas and services but also reflects the character and identity of Lusail. Buildings at Lusail City reflect more than a facet of this dynamic city and bring together modernity with a strong link to the rich cultural heritage of Qatar.

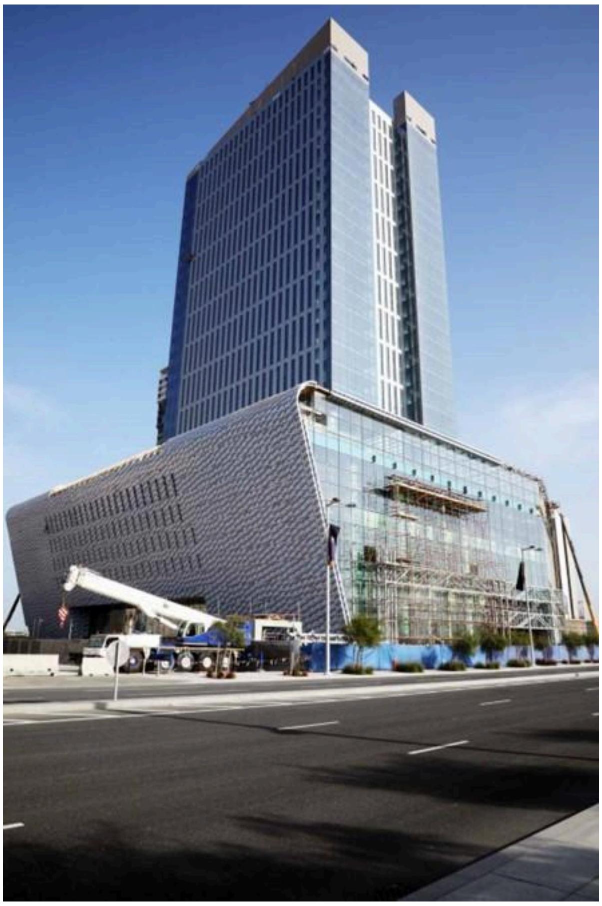


Figure 2: Marina Com-13 at Lusail, Qatar.

Ornamentation of surfaces has a long tradition in Islamic and local Gulf Design. The richly patterned buildings of the Moorish palaces at Alhambra have a direct lineage to the Mosques and Palaces of the Gulf region. These buildings have in common their strong and simple forms containing a surprising amount of detail and ornamentation within their public spaces.

The building is a part of Qatar's development of a sustainable city – Lusail which is around 20 kms north of the Doha. The main source of energy is a District Cooling Plant providing chilled water to all the buildings within the Marina district.

Commercially, the owner of the project must pay the associated fees for the supply of Chilled Water to the District Cooling Services provider Marafeq Qatar.

4.3 Enhancing building performance through improved passive design parameters

As part of this research, the selected design parameters – external wall, window to wall ratio, glazing and external & internal shading devices were enhanced to improve the building energy performance.

Table 1 shows the improvement of each of these parameters with respect to the base case.

Design Parameters	Base Case	Proposed Case
Only Window to Wall Ratio (WRR)	Average – 65%	Average – 30%
External Wall U-value	0.568 Watts/m^2/K	0.17 Watts/m^2/K
Glazing U-value	2.1 Watts/m^2/K	1.3 Watts/m^2/K
External Overhangs	NA	Overhangs providing shading to
Internal Shading	NA	Daylight controlled automatic blinds

Table 1: Enhanced building passive design parameters.

V. RESULTS

5.1 Impact of the selected passive design strategies: sensitivity analysis of selected parameters

All the selected passive design strategies were simulated individually and then collectively to determine the impact on the energy consumption. In total, seven combinations were identified and simulated – base case being the current situation, or no strategy implemented and the best-case scenario being that all the identified strategies are implemented in the design of the building.

Figure 3 indicates the energy consumption of the building in all the analysed scenarios.

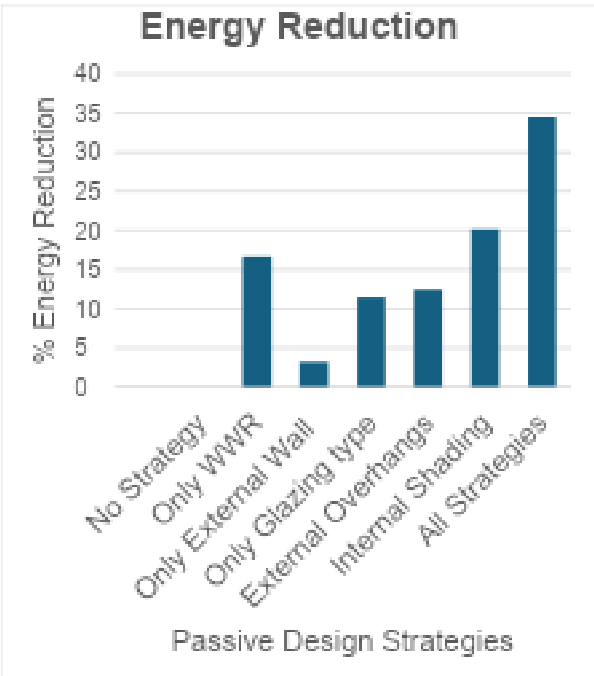


Figure 3: Reduction in thermal energy demand by implementation of identified passive strategies.

Figure 4 below shows the impact on the Energy Utilization Index (EUI) based on the implementation of identified passive strategies. It can be concluded that the EUI reduces the most with the implementation of all the strategies. However, this may not be feasible in certain cases, hence the project team needs to identify the best scenario for the design building and proceed accordingly with the design strategy.

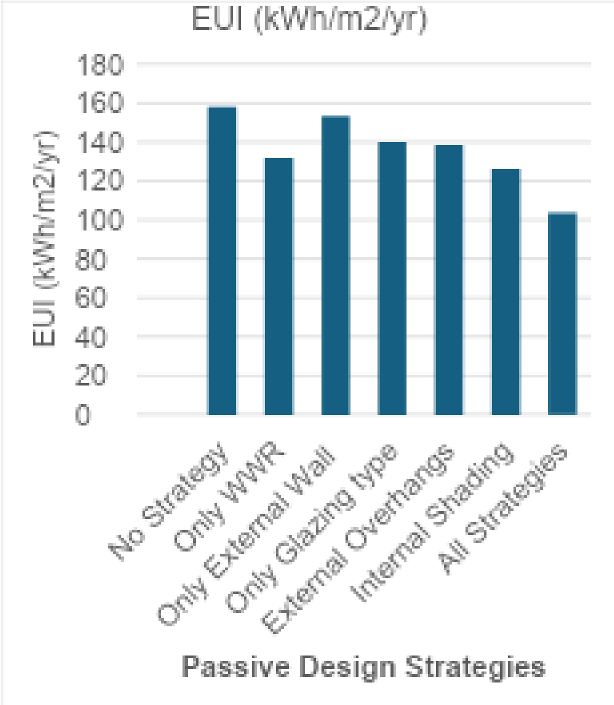


Figure 4: Reduction in thermal energy demand by implementation of identified passive strategies.

5.2 Environmental impact of selected passive design strategies

The built environment plays a significant role in global energy consumption and its associated environmental impacts. Buildings account for a substantial portion of the world's energy use, with estimates suggesting that they contribute to nearly 40% of global energy consumption and over 30% of total greenhouse gas emissions. This energy is primarily used for heating, cooling, lighting, and powering appliances, with much of it generated from fossil fuel-based sources, leading to high carbon footprints. As urbanization increases and the demand for more buildings grows, so does the urgency to address energy use in this sector.

Reducing energy consumption in buildings has the potential to deliver major environmental benefits. By implementing energy-efficient technologies, incorporating renewable energy sources, and adopting sustainable building practices, the carbon emissions associated with the operation of buildings can be drastically reduced. These measures not only mitigate climate change but also contribute to improved air quality, resource conservation, and reduced strain on energy grids.

Moreover, energy reduction strategies in buildings align with broader sustainability goals, such as those outlined in the Paris Agreement and other international climate commitments. As nations strive to meet their emissions reduction targets, improving the energy efficiency of new and existing buildings is recognized as one of the most cost-effective and impactful solutions.

This introduction provides the foundation for exploring how reducing energy consumption in buildings can positively affect the environment, focusing on key strategies, technologies, and policies that can drive significant reductions in energy use and emissions within the built environment.

Table 1 below indicates the total Carbon Emissions by implementing the passive design strategies. All the 7 scenarios are considered in this and as concluded from the table below, the amount of CO2 emissions by implementing all the identified strategies is the maximum (around 34%).

Passive Cooling Strategy	Yearly Energy Consumption (kWh/yr)	CO2 Emissions (kgCO2/kWh)
No Strategy	7,892,622	3,969,989
Only WRR	6,572,612.25	3,306,024
Only External Wall	7,641,690.66	3,843,770
Only Glazing Type	6,984,678.87	3,513,293
External Overhangs	6,909,349.50	3,475,403
Internal Shading	6,300,229.23	3,169,016
All Strategies	5,166,297.72	2,598,648

Table 1: Amount of CO2 emissions by implementation of identified passive design strategies.

VI. DISCUSSION

Climate change will impact the built environment in the Middle East countries as global warming will increase the cooling energy requirements. Nevertheless, there is a potential for the built environment to reduce its cooling demand by adopting passive design strategies and converting to more renewable energy sources.

This paper sought to explore the effectiveness of selected passive cooling strategies in commercial buildings from warm climates, defining performance ranges based on the assessment of multiple scenarios and climate contexts. This task was conducted through the statistical analysis of results from documented research experiences, to define overall ranges and boundary conditions; and through software simulation of selected parameters to isolate their impact under a controlled experimental setup.

It was concluded both by the review of existing research and the simulation scenario for the selected building that the energy savings due to effective passive design strategies have a greater impact than having efficient active systems installed.

VII. CONCLUSION

The energy savings by the implementation of all the suggested strategies were at 34% which is a remarkable savings in terms of energy as well the associated carbon emissions. This would mean that the carbon emissions required to produce the energy demand of the building will also reduce significantly thereby improving the overall environment of the city. The implementation of individual strategy resulted in the energy demand savings ranging from 3% - 20%.

Therefore, a combination of the strategies can be implemented in the passive design of the building depending on the feasibility for project and move towards energy efficiency. Furthermore, the reduction in the energy demand would make sure that the equipment and other active systems installed within the building are of lower capacity and thereby further reducing the energy consumption.

The findings can be considered as a first step towards providing useful inputs to the designers and developers of future buildings in hot and arid climate. A case specific analysis is important to determine the best strategy or combination of strategies that can be implemented keeping in mind the local rules and regulations, design and concept of the builder and energy demand. The government regulations and impositions also play a crucial role in incorporation of passive design strategies both in new as well as existing building.

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