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Climate Change Mitigation Mechanisms for Buildings in Hot Arid Regions (Case study: Tall buildings of MENA region)

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ABSTRACT
It is generally known that there has been a massive interest about the climate change and its significant impacts on health, weather, social and even economic activities. Nevertheless, the Hot arid regions are mostly impacted by these consequences. It is well known that Tall buildings are considerably designed for iconicity and symbolism in most cultures. There is a strong evidence that most of the MENA (Middle east and north Africa) region cities are extremely using the energy efficiency techniques in most of their buildings especially for the tall buildings to adapt the consequences of the climate change despite of the UNEP (united nations environment program) official report which documented that there are economic and financial barriers for especially the developing countries in applying most of the energy efficiency technological techniques in buildings due to its expense. A gap in knowledge was found regarding the minimal focus of the natural air circulation design based for Tall buildings in most of the middle east countries to create a better natural ventilation and air flow tightness. The paper presents a theoretical basis and cases study analytical strategies. Adaptation mechanisms for tall buildings in the hot arid regions are also discussed. Summarily, our conclusion provide evidence that the environmental design of buildings must be the preliminary first action for facing the negative impacts of climate change in hot arid region developing countries then any other technological aids will be highly recommended if applied.

Keywords: *Climate change; Adaptation; Tall buildings; Hot arid region; Mitigation*

1. Introduction

It has been reported according to the UNEP (united nations environmental program) that the massive impact of climate change had seriously come across with significant intense consequences all over the world [1]. Accordingly, the last few years, there has been a considerable interest about the climate change, and its massive impact on several crucial sectors such as weather patterns, health impacts, and even social and economic activities. In September 2020, unprecedented typhoons hit northeast china for two weeks followed by freezing rains in November. Massive power failure was a natural consequence then. The very recent natural hazards make people addressed the negative climate change impact on human beings as well as the living environment. According to the intergovernmental panel on climate change report (IPCC), the vital source for warming is the exceeding of carbon dioxide concentration in atmosphere [2]. An ever increasing body of literatures shows that deadly heat waves hit cities such as Canada and Pakistan due to the scorching temperatures, which was the main reason for setting up fires in other cities as Greece and Siberia. Other literatures reported an intense flooding in Germany, as well as a prolonged drought in Madagascar. Hot arid regions specifically are expected to experience significant changes due to the climate warming. There are different expected scenarios based on several factors such as the changeable rate of precipitation, the feedbacks of vegetation climate as well as the effects of carbon dioxide concentration on vegetation. All these challenging factors can easily affect the modelling of climate change in arid regions. An unexpected arid ecosystem response to the exceeding level of carbon dioxide concentration and climate warming is significantly reported [3]. Climate change is an emergent complex disaster which needs supportive techniques and mechanisms through all the negatively impacted sectors.

According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,32% of the worldwide energy use goes to buildings. This study reported that buildings accounted for 19% of greenhouse gas emissions, third of the total percentage of black carbon emissions as well as third of the fluorine emissions. These rates are expected to exceed due to urbanization and the climate change issues. However, despite the several reviews in the literature that addressed the buildings 'misuse of energy, the building sector remains the easiest sector to work on it [4-6]. Cities are hopefully standing for energy conservation mechanisms as well as emission reduction techniques for existing and new buildings. Mitigation and adaptation techniques are fully studied in a wide range to deal with the negative impact of climate change on buildings.

2. Research Problem

In terms of adaptation and mitigation of climate change for buildings in hot arid climate, there are various solutions most of them technically implemented through the building envelopes of buildings such as energy efficiency smart systems and techniques as well as smart cooling mechanisms inside the building to maintain a satisfying level of thermal comfort for occupants. Most of the market proposed solutions are considerably with high expense and according to the UNEP (united nations environment program) for sustainable buildings and climate change official report [1], there are economic and financial barriers for especially the developing countries in applying most of the energy efficiency technological techniques in buildings due to its expense. Effective solutions are in a massive need for tall buildings to adapt and mitigate the negative impact of the climate change.

3. Research Objectives

The aim of this study is achieving a practical solution to adapt and mitigate the negative impacts of climate change for tall buildings in hot arid climate to aid the implementation of energy efficiency smart systems if applied, mostly for the economic conditions of developing countries.

4. Research Methodology

The study presents a mixed strategy of theoretical data collection basis and cases study analysis strategies. A theoretical data collection strategy was performed through professional publications and scientific journals in order to achieve a designing criteria for the proposed solution. Three case studies had been analyzed based on the concluded criterion located in the selection studying area (MENA region). A frame work conclusion had been performed to be implemented as a proposed solution for the research problem.

5. Theoretical Study

5.1 The Definition of Climate change

Several international organizations have proposed definitions for the climate change expression. According to the United Nations, Climate change is defined as basic natural shifts in temperatures and weather patterns in a long term. However, since 1800, the major cause for climate change was surprisingly the negatively impacted human activities such as burning fossil fuels such as coal, and oil which is the key role in production of heat trapping gases [7].

Moreover, according to NASA, Climate change is defined as the usual changeable weather in a place. This change could be in the rain capacity, or an exceeding rate of temperatures for a certain time as shown in Figure 1. It could be also on a wider scale. This change might happen for the whole Earth's climate including a change in the usual temperature or in the weather patterns for a certain interval of time. NASA reported that the planet's climate might take millions of years to identify a change [8]. Also, the Australian academy of science referred to the climate change as a change in weather patterns followed by noticeable changes in land surfaces, seas and oceans, in decades or more [9].

5.2 Impacts of climate change in Hot Arid regions

In general, the impact of climate change can be determined through unusual hot weather patterns, droughts, fires, rising in sea levels, damaging storms, as well as melting the polar ice [7]. However, in a hot arid region as the middle east and northern Africa region (MENA region) which has been classified as one of the hottest spots on earth [10], several studies have reported that the countries of the MENA region will be expecting an exceeding rate in temperatures, and heat waves followed by long periods of droughts, as well as a decline in precipitation [11,12]. The negative impacts of climate change will be aroused in the larger cities of the region. Moreover, the inner cities' temperatures will be higher than the rural areas by 2-3 Celsius degrees due to the effect of urban heat island [13]. Most of the studies put an emphasis on the consequences of the urban communities' health [11].

Beside the water shortages and heat waves, other studies have definitely reported a higher 4 Celsius degrees global warming, which means an increasing in the mean of summer temperatures of the region by 8 Celsius degrees [14]. Studies also identified a 75% declination in water run off with 60% exceeding percentage in land aridity in most of the region countries [14]. Negative impact of climate change is unfortunately effecting the developing process of energy systems, land and water resources as well as people's health.

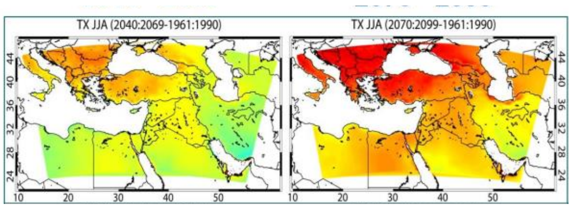

Figure 1- Changeable patterns of the mean maximum temperatures in June, July & August [36]

5.3 Impacts of climate change in Hot Arid regions on Buildings

There is no doubt that the impacts of climate change affected negatively on the building sector as well. The intense of heatwaves and the high rise of weather patterns have an extreme effect on the energy demand as well as the architectural design of buildings. New environmental approaches in designing new buildings should be considered [15].

Other studies reported the increase in energy consumption of buildings, the negative impact of overheating on health issues, the dryness of soil and the increasing of cracks as a result of the climate change [16]. Some authors assumed that the cooling process will count for the greatest amount of energy demand in buildings in hot arid regions and this increasing in energy consumption will have a significant effect on the main energy system operation [6].

The internal services of buildings, the indoor air quality are also negatively affected. The rise of carbon emissions of buildings and the peak demand of building electricity are also highly expected due to the cooling process of HVAC systems for buildings [17]. In this area, researches pointed out that the unusual high rise weather patterns will negatively affect the existing HVAC systems' efficiency which may lead to a decrease in their durability especially in old buildings [5].

5.4 Adaptation and mitigation mechanisms for buildings in hot arid regions

5.4.1 Building Envelope

A building envelope (facades) is considered to be one of the most effective ways of mitigation mechanisms for buildings in the hot arid regions. The building envelope is defined as a physical partition located between inside and outside the building, with benefits of water, air, heat and light resistance as well as noise transmission [18]. The building envelope consists of foundation, walls, roofs, and ceiling including the insulation barriers.

Iran (one of the MENA region countries) has established a reviewing study about the energy saving technologies of the building envelopes. The study has reported several features for the envelopes including effective shading, low cost, reflective layers of roof elements, high operated, high light covering, covered glasses [19].

Moreover, Morocco (also one of the MENA region countries) has discussed the important role of the phase change material in decreasing the indoor temperature of buildings in order to make efficient of the external walls and their thermal performance [20]. They also studied the effectiveness of the clay-sawdust composite material as a fencing material to the exterior walls. They reported massive reduction of energy consumption using this material specially in conventional buildings by 21% and in residential buildings by 5.3% [21].

In addition to the study reported by Netherlands while studying the building facades and its effectiveness in Dubai hot arid climate conditions. They have examined the effectiveness of the bio-based cladding of external walls in buildings. The bio-based cladding consists of recycled textiles, water treatment wastes, toilet paper, reed, grass and polyester resin. The study reported a massive reduction in the indoor temperature, reduction in energy consumption as well as the optimal impact of these bio-based materials on environment [22].

Several studies have recommended the usage of the external shading panels over the building façade with a research based selection criteria and design approaches according to the location, climate, daily sunlight direction in order to improve the energy savings as well as to decrease the indoor temperature of spaces [23] as shown in Figure 2. Also, this has been recommended for the high rise buildings.

Figure 2 - Installing shading panels on the building façade [37]

In terms of exploitation the solar energy in most of the MENA region countries where the daily sunlight period especially in summer time is excessively high. Several published articles have recommended the usage of photovoltaic systems with both types ground mounted and building integrated in order to make the

maximum efficiency of the building skin where the PV modules are being installed in order to provide the buildings with the sufficient amount of energy, power or even electricity [24].
Beside the solar energy, it is extremely supportive to report the massive implications of bioenergy in buildings. Several studies have reported the production of biogas from wastes, and energy crops which is severely important for renewable energy. Also, the usage of biomass in cooling processes without the supporting of any mechanical mechanisms is also been recommended by several studies. This can be achieved with the support of the biomass boilers, and absorption – adsorption chillers pumps [25]. In this track, we have to announce the massive impact of microalgae in reducing the carbon dioxide emissions of buildings. The usage of microalgae photo-bioreactors on building skin has proven a significant effect of the thermal insulation systems of buildings and can easily be used as adaptive sunshades elements [26] as shown in Figure 3.

Figure 3 - Bioreactors application facade in Hamburg, Germany [38]

5.4.2 Solar chimney & cooling towers

Several studies from the MENA region countries has examined the effectiveness of the solar chimney concept in buildings. They have also examined the effectiveness of the mixed use of the phase change material (PCM), cooling tower with the solar chimney at the same time. The studies reported an optimal declination in the indoor temperature of building spaces. They have also recommended the usage of this integrated technologies in the high rise buildings especially in Egypt. [27]

5.4.3 Dehumidification

Other studies reported the efficiency of an integrated cooling system especially for hot climates, this cooling system includes a supply for cooling air, and evaporative cooler especially for the occupants. These integrated cooling systems provide supporting the thermal comfort level of spaces inside buildings as well as controlling the relative humidity [28].

5.4.4 Passive cooling

Passive cooling is deeply recommended in hot arid regions. Several studies examined the effectiveness of passive technology on the roofs of buildings, including white paint with insulated features. The ceiling temperature has been declined by 13 degrees Celsius, and the heat flux has been decreased by 66% [29]. Other studies demonstrated the massive implications of passive cooling technologies in buildings, it is reported that the heat increasing had been declined by using shading panels and cooling paints. Also, the indoor temperature of space can be decreased by increasing the gypsum plaster thickness and using natural ventilation as well [30]. Thus, the type of building, the occupancy rate, the wind speed and direction are to be concerned while using this technology.

5.5 Environmental design for Tall buildings

Tall buildings are considerably designed for iconicity and symbolism in most cultures. Greenest tall buildings where "the green meets the blue", this expression is referring to the sustainable green architectural principles applied in tall buildings. New materials and green techniques have been enhanced in this kind of buildings in order to achieve resources efficiency, and be more economically as well. In addition to energy conservation objectives that determines several design variables of tall buildings designing process.

Additionally, there is no doubt that above all the negative impacts of climate change on buildings in any hot arid region are the intensive heat waves and the high rise of weather patterns. These impacts can easily guarantee the high demand of energy usage in buildings that leads to a rise in carbon dioxide emissions. And according to the UNEP (united nations environment program) for sustainable buildings and climate change official report [1], there are economic and financial barriers for especially the developing countries in applying most of the energy efficiency technological techniques in buildings due to its relatively high expense. To fill this gap, the environmental design for buildings that promotes a high indoor air quality becomes the best solution in order to aid the concept of applying intensive energy efficiency technological techniques. The environmental design of buildings must be the preliminary first action for facing the negative impacts of climate change then any other technological aids will be highly recommended if applied.

Creating designs that minimize the natural resources usage and using economic local resources instead, un affecting the ecological balance, in addition to reducing the negative impacts of buildings on environment are considerably the major aims for having sustainable design for buildings. Specifically, a sustainable design for high rise buildings can be summarized to three parts: ecological parameters, economical parameters, and sociocultural parameters [31].

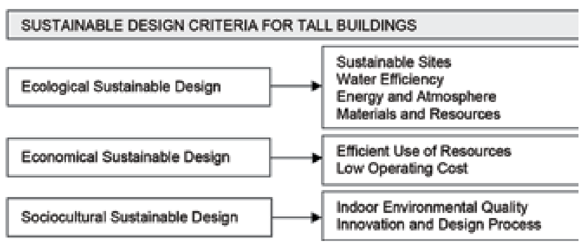

Figure 4 - Sustainable design parameters for Tall buildings [39]

Each sustainable design parameter has three subtitles considering the environmental design of tall buildings. The ecological sustainable design parameter promotes sustainable sites, efficiency of water, energy and atmosphere, materials and resources. The economical sustainable design parameter promotes efficiency of resources usage, and guaranteeing a low cost of operation. The sociocultural sustainable design parameter promotes the indoor environmental quality, and an innovative design process. According to the previous study, the tall buildings in a worldwide scale that are LEED (Leadership in energy and environmental design) certificated, had worked on the sociocultural sustainable design parameter (SCSD) more than the Ecological sustainable design parameter (ESD), and the Economical sustainable design parameter (ECSD) [32] as shown in Figure 4. Therefore, we can conclude the importance of the sociocultural sustainable design parameter in enhancing a better environmental tall building.

There are a lot of building performance assessment systems in terms of indoor environmental quality such as LEED, BEAS, and BREEAM. According to studies, the building performance assessment BEAS is widely used more than BREEAM and even the LEED program all over the world. The BEAS system is being rated by 23.5 as a significant weight for its usage all over the world while LEED is being rated by 22 and the BREEAM is being rated by 15 [33].

The BEAS building performance system in terms of indoor environmental quality has rated the thermal comfort parameter as the most important parameter in the indoor environmental quality. The Thermal comfort parameter has been rated by 16.4 % from a total parameters percentage 23.5% in the BEAS assessment system [33].

Thermal comfort is defined as a subjective evaluation for the occupant's satisfaction of the interior thermal environment. There are various variables that affect the heat balance of body and its thermal comfort perception. Some of them are personal parameters such as occupant activity and clothing, and the others are environmental parameters such as air velocity, air and radiant temperatures, humidity [34].

There is such a massive need for thermal comfort environmental design for buildings in order to aid the technological mechanisms for guaranteeing the best performance, yet the maximum energy savings as well specifically in tall buildings where mechanical and technological systems are widely taken place. And in order to set up a thermal comfort environmental design solution, further studies have been compromised regarding the designing aspects that affect the thermal comfort of a space. Several studies promote significant designing aspects that primarily affect the thermal comfort of spaces as the following:

-Providing Insulation systems

-Controlling heat gain in spaces

-Promoting air tightness and natural ventilation

The previous designing aspects that mainly affect the thermal comfort in spaces are first providing insulation systems which minimize heat gain in summer seasons and minimize heat loss in winter seasons, second controlling the heat gain in spaces in order to maximize the satisfaction of thermal perception for occupants, and finally enhancing the circulation of air tightness through all spaces as well as promoting a viable natural ventilation.

In this part of data collection studies, this manuscript has concluded the following comprehensive designing aspects as shown in Table 1 with adaptation and mitigation mechanisms for tall buildings to adapt the climate change in hot arid regions such as the MENA region.

Table 1- Comprehensive designing criteria for Thermal comfort environmental design solutions of Tall buildings.

Aspects affecting the thermal comfort of a space	Adaptation and mitigation mechanisms to achieve these aspects
1-Providing Insulation systems	Building Envelope insulation mechanisms
2-Controlling heat gain in spaces	Dehumidification & cooling mechanisms
3-Promoting air tightness and natural ventilation	Cooling towers, passive cooling designs and other natural ventilation design solutions

6. Analytical Study

In this sector, the principle focus is on analyzing case studies of Tall buildings in MENA region, proposing adaptation and mitigation mechanisms in order to face the climatic change of the hot arid region of their location. Each project has been analyzed separately according to the previous criterion concluded in the data collection section.

6.1 Qatar – Doha Tower

Architect: Jean Nouvel
Category: Office building
Construction year: 2012
Location: Qatar - Doha
Building height: 238.1 meters
Awards taken: CTBUH Skyscraper Award 2012

Table 2- Comprehensive designing criteria for Thermal comfort environmental design solutions of Doha Tower.

Aspects affecting the thermal comfort of a space	Adaptation and mitigation mechanisms to achieve these aspects
1-Providing Insulation systems	-An iconic façade cladding depends on the orientation of building to avoid solar radiations. Opacities: 25% at north elevation 40% at south elevation 60% at east and west elevations
2-Controlling heat gain in spaces	Energy saving conditioning system
3-Promoting air tightness and natural ventilation	None

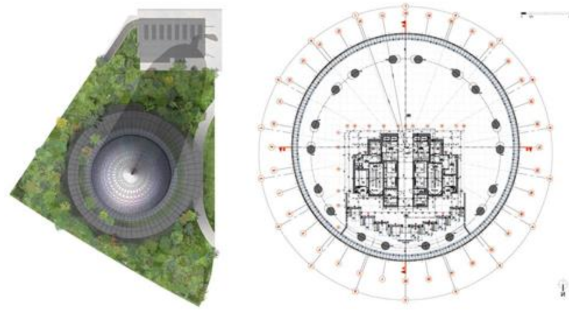

Figure 5 – Doha Tower [40]

6.2 UAE – Al Bahar Towers

Architect: Aedas Architects
Category: Office building
Construction year: 2012
Location: Abu Dhabi - UAE
Building height: 145 meters
Awards taken: CTBUH Innovation Award Winner

Table 3- Comprehensive designing criteria for Thermal comfort environmental design solutions of Al Bahar Towers.

Aspects affecting the thermal comfort of a space	Adaptation and mitigation mechanisms to achieve these aspects
1-Providing Insulation systems	-An automated responsive façade consists of 2000 shading devices that are connected to the building management system, these shading devices are responsible for reducing the solar radiations moved inside the spaces through stretched polytetrafluoroethylene. -The shading devices were located at the south, east and west facades.
2-Controlling heat gain in spaces	Energy saving conditioning system
3-Promoting air tightness and natural ventilation	None

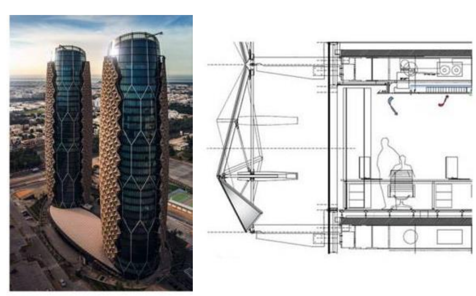

Figure 6 – Al Bahar Towers [40]

6.3 UAE – Iris Bay
Architect: Atkin Architects
Category: Office building
Construction year: 2015
Location: Dubai - UAE
Awards taken: The CTBUH Best tall building in Africa 2016

Table 4- Comprehensive designing criteria for Thermal comfort environmental design solutions of Iris Bay

Aspects affecting the thermal comfort of a space	Adaptation and mitigation mechanisms to achieve these aspects
1-Providing Insulation systems	- The south west and north east facades are with fewer openings and photovoltaic cells to avoid the transfer of heat gain into spaces as well as to take advantage of solar energy. - The north west façade has a zigzagging curtain wall to permits the transfer of natural ventilation and sun light.
2-Controlling heat gain in spaces	Energy saving conditioning system
3-Promoting air tightness and natural ventilation	The convex façade designing promotes negative pressure areas that transfer the air into the building

Figure 7 – Iris Bay Tower [40]

7. Discussion
Along with the previous case studies analysis, it has been declared that a minimum focus has been applied on the environmental design of building regarding the enhancement of natural air circulation through all spaces. The iconic designs of tall buildings can be symbolic and also aid the natural ventilation path at the same time even with a low percentage as the Iris bay tower located in United Arab Emirates UAE. An impressive emphasis on implementing technological building envelopes with special energy efficiency features and variety in iconic Motiva forms is taking place however, neglecting the cost effectiveness factor and the high expense of these mitigation technological mechanisms is not an optimal solution.
As previously mentioned, there are economic and financial barriers for especially the developing countries in applying most of the energy efficiency technological techniques in buildings due to its relatively high expense according to the UNEP (united nations environment program) for sustainable buildings and climate change official report. And to fill this gap, the environmental design for buildings that promotes a high indoor air quality becomes the best solution in order to aid the concept of applying intensive energy efficiency technological techniques.
The environmental design of buildings must be the preliminary first action for facing the negative impacts of climate change then any other technological aids will be highly recommended if applied. Tall buildings must be environmentally designed first in terms of promoting the air circulation and thermal comfort factor, then more energy efficient technologies are very welcomed for achieving the best energy conservation rate. It is the role of the architect first. Designing for the best air tightness and natural ventilation as a first designing objective can easily be a more than effective solution in most of the developing countries which may affect the rate of usage the high expense technological mitigation systems. For Egypt, we recommend specific air tightness and natural ventilation designs for tall buildings especially in the new Egyptian capital.
Stack ventilation can be the optimal architectural environmental design solution for better air tightness and natural ventilation especially for Tall buildings. Stack ventilation or the chimney effect as known in most references, transfers the airflow that comes from the difference in air pressure, and temperature through the natural force in between the indoor and outdoor environments [35]. For the best environmental designing solution, the authors recommend using the stack flue concept or the stack atrium concept as shown in Figure 8 while designing tall buildings.

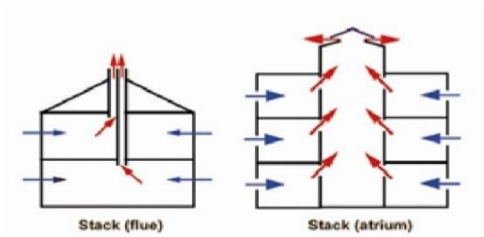

Figure 8 - The stack flue and atrium ventilation techniques in buildings [41]

It is well proven in many real case studies the success of choosing the stack ventilation as a preliminary source of natural ventilation in Tall buildings in un-similar climate regions such as East gate building in Zimbabwe, and CH2 building in Australia as shown in Figure 9. Both buildings had chosen the stack flue ventilation technique as an environmental designing concept for better natural ventilation access. The stack effect can be the best environmental designing concept that suits the nature of tall buildings with respect to the height, the structure and even the function. It can be the first aid for the architect to firstly design the tall building with respect to the stack ventilation concept so as to enhance a better quality of air tightness and natural ventilation to the building. Then comes ahead the role of applying intensive energy efficiency technological techniques that will positively promote the impacts of the climate change in the chosen region.

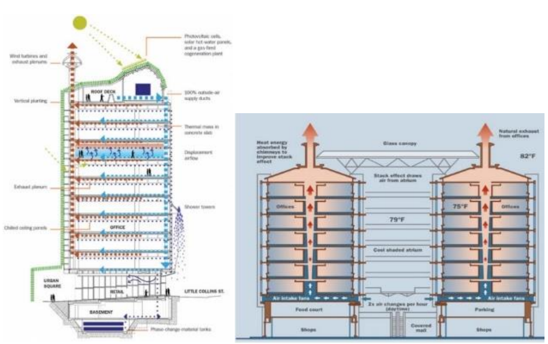

Figure 9 - Left: The Ch2 building in Australia, right: The East gate building in Zimbabwe [40]

8. Conclusions

The current study confirmed the air tightness and natural ventilation design based for Tall buildings as an effective solution for the research main problem which is the economic and financial barriers for especially the developing countries in applying most of the energy efficiency technological techniques in buildings due to its relatively high expense as available solutions for adaptation and mitigation for climate change in buildings in hot arid climates.

Our results find evidence about the minimal focus of the natural air circulation design based for Tall buildings in most of the middle east countries except for UAE where there are recently proposing solutions for this design based direction. Revealed differences have been reported in the analytical section for implementing various technological building envelopes with special energy efficiency features and a variety in iconic Motiva dynamic forms as well. Symbolism and iconicity of the architecture of tall buildings have also been reported. Creating stack ventilation techniques in the designing process of a tall building might be an effective designing solution for promoting air tightness and natural ventilation which has been proposed in our current study in order to aid architects in understanding the enhancement of air circulation through spaces in Tall buildings.

The Following proposed framework has been achieved for architects in order to avoid stucking in financial problems regarding the application of high expense energy efficiency techniques in Tall buildings.

First: The Designing Process

It is better to achieve an environmental designing solution first as a designing aid concept for the tall building. The authors recommend using the Stack ventilation techniques for its proven success in promoting the natural ventilation and air tightness in tall buildings in various climate regions

Second: Implementing intense energy efficiency techniques

As a second step, and with reference to the financial budget and the cost effectiveness factor, the authors recommend (if the financial budget permits) applying energy efficiency techniques as for the building envelope or inside the building to aid facing the climatic changes problems that we are facing nowadays.

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