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Assessment of Carbon Dioxide Emission and Its Impact on High-Rise Mixed-Use Buildings in Egypt

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The American University in Cairo

The School of Sciences and Engineering

ASSESSMENT OF CARBON DIOXIDE EMISSION AND ITS IMPACT ON HIGH-RISE MIXED-USE BUILDINGS IN EGYPT

A Thesis Submitted to

The Department of Construction Engineering

In partial fulfillment of the requirements for the degree of

Master of Science in Construction Engineering

By

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B.Sc. in Construction Engineering, 2017

The American University in Cairo

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May 2021

DEDICATION

This thesis work is dedicated to my loving Mother, Laila Shalaby, which was one of her last wishes to pursue this MSc before she passed away in 2015. May Allah rest her soul in peace.

This thesis work is also dedicated to my dear Father, Salah Hamza, my role model who passed away in 2020, although he is no longer with us, he will always continue to give me the inspiration to succeed. May Allah rest his soul in peace.

This thesis work is also devoted to my beloved Wife, Hana Mostafa, who has been and will always be my source of support and motivation throughout my life and all the hard times that comes with it and definitely throughout this thesis.

ACKNOWLEDGEMENT

In the Name of Allah, the Most Merciful, the Most Compassionate all praise be to Allah, the Lord of the worlds; and prayers and peace be upon Mohamed His servant and messenger.

There are several people without them this thesis might not have been written, and to whom I am significantly thankful.

I am thankful and grateful to Prof. Dr. Mohamed Nagib Abou-Zeid for his patience and guidance. He has been very generous with his knowledge, and his trust in my abilities has made my journey more rewarding. It has been a pleasure working under his supervision.

To my dear Father, Salah Hamza, who gave me the steppingstone and the motive to pursue this thesis and guided and encouraged me through-out the process.

To my beloved Wife, Hana Mostafa, who has been a source of encouragement and inspiration to me throughout my life. A very special thank you for your patience and support throughout the months of writing, and for helping me keeping myself focused and determined to realize my true potential and try to make this contribution to our world.

A loving and genuine thank you to Mostafa Yousry, my Father-In-Law, and Hoda Abo El Fetouh, my Mother-In-Law, who have been a source of support and encouragement throughout the harsh times.

Special thanks to my Friend, Marwan El-Haddad, who played important roles along the journey, as we mutually engaged in making sense of the various challenges we faced and in providing encouragement to each other at those times when it seemed impossible to continue.

ABSTRACT

With Egypt's vision of 2030 focusing on sustainable development with a true emphasis on Carbon Dioxide (CO_2) emission reduction in the newly built cities and high-rise buildings, efforts are exerted on various levels towards accomplishing the vision's goals. This is achieved through multiple tools and models associated with aiding the reduction of carbon emissions, yet not a clear one was introduced for the mixed-use buildings in Egypt.

Through this work, a significant gap was identified with respect to high-rise buildings carbon emission assessment in Egypt. This was a main driving force for this work in an attempt to develop a computational model that can be useful in this regard. The investigation is undertaken with a goal to pinpoint existing sustainability methods used in the development and design of the world's high-rise mixed-use infrastructures. In addition, this work attempts to identify adequate approaches that can contribute to a more effective, environmentally safe, and space-efficient construction of mixed-use high-rise building in Egypt. This aims ultimately at defining the driving factors of carbon dioxide emissions relevant to the building phase and recommend strategies to encourage more environmentally sustainable approaches where appropriate. This study develops and evaluates a comprehensive carbon model framework for high-rise building construction and operation activities and testing the model's validation through analytic analysis.

The outcome of this study should contribute to a much-needed roadmap to reduce Carbon Dioxide (CO_2) footprints in Egypt and possibly lay the groundwork to replicate the study in other building sectors and regions. This would also develop sensitivity analytics to envision carbon emissions of buildings within the construction phase and operational phase using various sustainable construction materials and mixes-primarily for concrete, bricks, and steel, and in the operational phase using alternative sustainable products primarily for lighting, air conditioning systems, water heaters, and window glazing. Similar to other work, future work should be resumed to further develop, enhance and adapt this model in order to suit the nature of projects, service conditions together with other parameters.

Keywords: (Carbon Dioxide, Mixed-Use high-rise buildings, Construction phase, Concrete, Bricks, Operational Phase)

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

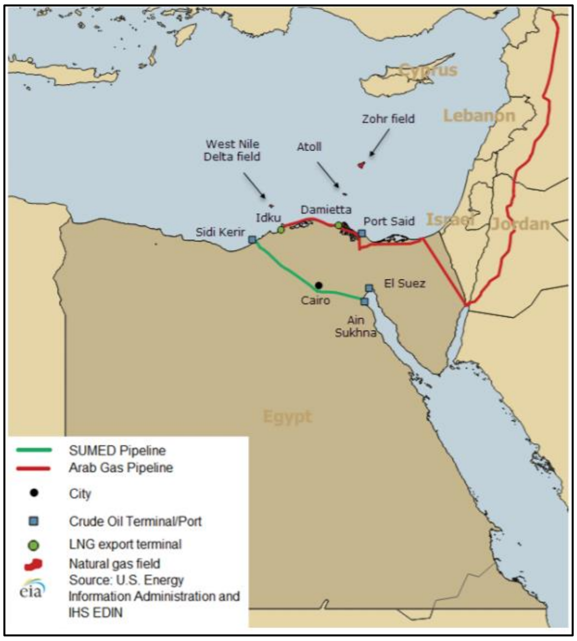
Nowadays, the major environmental issues that face the planet's future have grown to be a significant problem in the everyday life reflected in media reporting, and political debates as consequences of multiple sources of pollution and emissions which continue to escalate, damaging soil, water, climate, triggering global change, endangering wildlife environments and animal extinction, increasing forest fires, and degradation of the rainforests worldwide, which are expected to be entirely deforested by the mid of 21st century. The fires in Thailand and Australia that took place at the beginning of 2020 are an instance of day-to-day environmental damage. Sustainable development is essential to safeguard the atmosphere. In 1987, the World Commission on Environment and Development (WCED) issued a Sustainable Development study, known as the 'Brundtland Report' (United Nations, 1987). WECD's definition of sustainable development was ‘Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs’ (United Nations, 1987).

A variety of sectors are affecting a country's sustainable development. One of which is the construction industry, which is highly necessary for sustainable growth because it needs power, water, sites, and resources to create and maintain infrastructure and projects. Therefore, both the structures and the construction sector have explicit and implicit environmental impacts. When constructing a sustainable building there are several considerations. These sustainable construction measures are: (a) efficiency of water; (b) efficiency of energy; (c) assets and raw materials; (d) quality of environment, and (e) treatment of wastes (Lowe, C., and Ponce, A, 2010) Every measure has a significant part to symbolize building's sustainability level and standard. Taking into account, energy use and Carbon dioxide emission in Egyptian buildings, consumption of energy and Emissions of carbon dioxide from residences and mixed-use buildings have increased by more than 40 percent of total energy consumption and CO_2 emissions as a result of rapid urbanization (US EIA, 2018). In addition, the amount of electricity required for buildings is projected to rise over the coming years; thus, energy conservation is a key and critical issue for the upcoming years. Consequently, Fossil Fuels stockpiles are declining, whereas their expected cost is growing too fast. Egypt's generation ability in 2013 was 27 GW, the majority of which is powered by natural gas, and renewables (such as hydropower) produce less than 6 percent (US EIA, 2018).

The population of Egypt has risen significantly in the previous decades, exceedingly approximately 1.3 million in 2020, suggesting an estimated annual growth of 1.8 % (United Nations Population Division, 2020). Due to the present pace of evolution, it is projected that by 2030 Egypt's population will reach 118 million, needing comprehensive capital preparation for handling and sustaining this population density most prominently in infrastructure. The majority of mixed-use buildings and high-rise residential buildings have a direct effect on the population. Demand for houses is rising due to population increase. This fast demographic development forced Egypt to shift into high-rise mixed-use buildings to house more residents in modern developments e.g., the Modern Administrative Capital and New Alamein Town. The definition of a High-rise building is considered to be a multi-story building starting from 30m high or 10 floors, while Mixed-Use definition is considered to be any building that combines three or more uses in one structure. The uses can be residential apartments, commercial retail stores, offices, hotels, and even a parking. Mixed-use buildings and Residential Buildings make up a large portion of emissions of greenhouse gases (GHG) which include Carbon Dioxide, Carbon Monoxide, Nitrous oxide, and methane explicitly (via building materials) and implicitly (via energy usage), and so can be defined as one of the driving forces of pollution. Methane is considered to be even more dangerous than Carbon dioxide having four times the global warming effect on the atmosphere (US EIA, 2018).

As a consequence of elevated demand for residential buildings or mixed-use buildings, the level of pollution will rise, and if this increase is not sustained in its most effective method, there is a definite risk of global climate change. The role of a residential or mixed-use building to GHGs largely depends on the following two factors: (i) resources utilized in their architecture, such as Steel, concrete, glass, and bricks (ii) the components for housing installed during their lifespan, such as appliances, heating/cooling, lighting, etc. The total energy performance and durability of a building are calculated by both factors. Choosing the correct and ideal type of materials whose energy-intensity production is low will go a long way in preventing emissions. Thus, design parameters with this optimization in mind should be made. In addition, it is important to ensure that materials have been obtained from eco-friendly manufacturers. Steel may be manufactured normally, for example, by means of the traditional Oxygen Blast furnace production route - a process that requires intensive energy; and/or by a more energy-efficient Electrical Arc Furnace production route. On almost every other building material, the same concept exists. Hence making sure that all building items are manufactured in the most energy-efficient manner will certainly contribute to reducing their pollution from production. The total energy they use is concluded by the contribution of residential or mixed building materials to emission levels. Consequently, energy use over the lifespan of a building would be related to the energy consumption rate of each component and the degree of building use. Architecture is essential to make sure a project will function easily and securely if a load of heating/cooling and lights are decreased, for instance, by means of controlling the heat and sunlight exposures at daytime. Moreover, procurement of fairly modern sustainability elements with low energy usage is often critical since, when utilizing the most energy-efficient high-rise building components, it will save a lot of pollution because of their constant use over the existence of a residential or mixed-use project.

1.2 GENERAL BACKGROUND ON EGYPT



Source: U.S. Energy Information Administration and IHS EDIN

Figure 1-1: Map of Egypt (Hopwood, 2020)

1.2.1 EGYPT'S LOCATION and GEOGRAPHY

Egypt's origin dates from 4000 B.C. Egypt's gross area is 1,001,450 square kilometers, divided inland area of 995,450 sq. kilometers and water spanning 6,000 kilometers squared as illustrated in figure 1-1 (Hopwood, 2020). In addition, it links three continents via the Mediterranean Sea: Africa, Europe, and Asia. Egypt's heavily populated governorate makes it a very competitive and diverse nation. The Greater Governorate of Cairo, Egypt's main urban city, is populated with about 20 million people (Hopwood, 2020).

1.2.2 DEMAND AND SUPPLY OF ENERGY

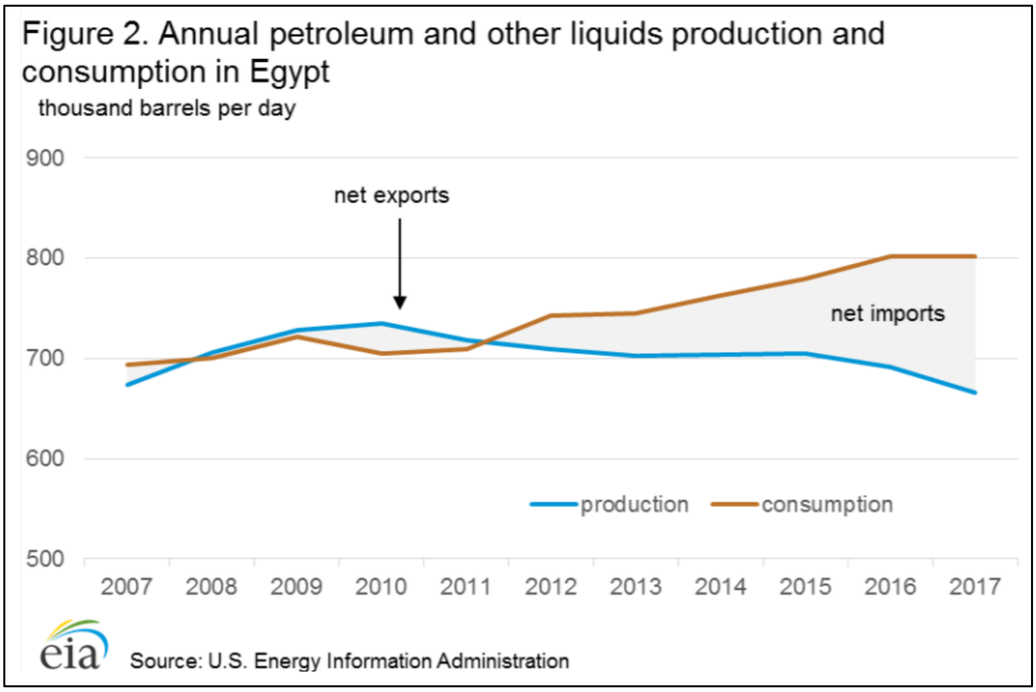


Figure 1-2: Egypt's Annual Oil Consumption (US EIA, 2018).

One of the several hurdles Egypt foreheads is meeting the increasing demand for oil with its decreasing production. For overall oil consumption in the past decade, an estimated yearly rise of 3% was reported, in 2017 totaling around 800,000 bbl./d. Figure 1-2 indicates, since 2010, utilization of oil in Egypt has outperformed its production. In addition, around 695,000 barrels/day was the gross energy output for Egypt in 2013 (US EIA, 2018).

In 2016, approximately electricity generation was 152000 GWh (Gigawatt-hours); it consists of 70 percent generated from natural gas, 20 percent generated from oil, and almost 10 percent generated from renewable energy sources (US EIA, 2018).

Egypt's energy use has risen, with peak demand rising at an average yearly rate of 8% in the last ten years, hitting around 38 GW in 2015/2016. The unprecedented rise in energy demand has generated fears about electricity shortage issues, energy efficiency, and power resource exhaustion; this growing energy use has contributed to significant environmental concerns such as pollution and global warming (Ahmed et al., 2011). This deficiency and inadequacy in resource output are attributed to the unregulated environment created by the fragmented and disorganized strategies pursued by the users of the building.

Creating standards, regulations, and laws and checking that owners, construction managers, and residents comply with them. In Egypt, this will be the cornerstone to effective green building promotion. Because of the global depletion of fossil fuel, a way to reduce the above major issue in Egypt is by adjusting to energies that are renewable, especially since 60 percent of Egypt's area has a solar energy density that is surpassing about 7.2 kWh/m2/ day. Throughout the Egyptian economy, the usage of green resources is very minimal as opposed to other regions across the globe. And in the meantime, the appeal for renewable energies is of utmost significance.

Additionally, the developments of renewable energy projects on-site have introduced the idea of buildings with zero-emission. (MER, 2020).

1.2.3 EGYPT'S WASTE MANAGEMENT

Egypt's greatest concern is waste management. As per ElHaggar, Egypt's Municipal Solid Waste (MSW) is one of the biggest, accounting for approximately 21 percent of the overall waste produced with an estimated fifteen million tons quantity (ElHaggar 2010). The growing amount of Egypt's Municipal Solid Waste will contribute to the depletion of natural resources and will impact the atmosphere and human health (ElHaggar 2010). In comparison, Egypt's average yearly building and destruction waste is about 4 million tons (ElHaggar 2010). Therefore, it is necessary to manage the growing waste quantity and reduce the amount of waste by closed-loop strategies. The waste production per capita in 2015 was approximately 200 kg; in which the cumulative MSW is estimated to reach 30 million tons (MT) by the year 2020 (Giz, 2014).

1.2.4 EGYPT'S EMISSION AND EFFECT OF GLOBAL WARMING

The per capita ecological impact in Egypt is continually rising. The rise in GHG emissions has resulted in black cloud formation. The world bank stated Egypt's carbon dioxide emissions went up to 2.5 metric tons/capita in 2016 as of 0.5 metric tons per capita in the 1960s (World Bank 2016).

Moreover, Egypt's emission of CO_2 rose as of 225 million ($MTCO_2$ e), a standard metric to calculate total emissions of CO_2 in 2005 to 275 $MTCO_2$ e in 2010 and are projected to go above 550 $MTCO_2$ e by 2030.

The five key emissions-driving areas are energy production, cement manufacturing, buildings, motor vehicles, and agriculture, with the first two driving 75 percent (US EIA, 2018). Out of these five stated areas, the three most important sectors to this examination are:

1. **Power:**

   It accounted for nearly 61.6 MTCO$_2$ e in 2005 and was projected to rise to about 210 MTCO$_2$ e by 2030, as energy demand is rising. The total power sector reduction capacity is around 56 percent, of which 37 percent can be achieved by reducing the demand for energy, particularly in the construction market (US EIA, 2018).

2. Cement:

In 2005, it contributed to about twenty-four MTCO$_2$ e and was expected a rise by 2030 to seventy-one MTCO$_2$ e. Thus, making it the greatest source of carbon pollution. The estimated capacity for the cement industry decrease is 14 percent. While cement will stay on the top CO$_2$ pollution sources consisting of nearly forty percent of pollution-related to the industry, so there is a need for increased attention on the production of cement (US EIA, 2018).

3. Buildings:

It contributed to about 62 MTCO$_2$ e in 2005 and is projected to rise to around 165 MTCO$_2$ e by 2030, primarily due to higher energy use in residential or mixed-use buildings. The average capacity for the reduction in the building industry is about 24 percent. Most pollution from buildings is mainly attributable to electricity consumption (called indirect emissions, which contributes to 65 percent of overall emissions). The construction industry is liable for nearly 2/3 of pollution (US EIA, 2018).

As the construction industry is the biggest of all industries and has a major effect on climate change (Sev 2011). As per Sev, freshwater use within buildings accounts for 17 percent, while recovered wood contributes 25 percent, whereas material and energy use accounts for 40% (Sev 2011). The evidence outlined in this part thus demands an urgent need to incorporate sustainable and construction strategies and programs into the Egyptian economy. Many of these projected changes in pollution are attributed to population growth, and this report emphasizes working with the main contributors to such pollutants and seeking methods for increasing its reductions in order to save the ecosystem from rapid destruction.

1.2.5 THE SUSTAINABLE REVOLUTION IN EGYPT

The Egyptian Government's newly introduced Egypt Sustainable Development as part of the Sharm El Sheik Economic Conference targets sustainability, the Egyptian economy’s development, and human assets (EGYPT SIS, 2015). The goals of the strategy include (1) increasing the energy sector's productive ability; (2) minimizing waste production and related costs; (3) enhancing the well-being of citizens; and (4) decreasing carbon dioxide emissions and greenhouse gases from different industries (EMPED, 2018). Therefore, sustainability can have a major role in the efficient execution of this policy via a green building grading system in the construction and building industries. (United Nations, 2018)

1.3 PROBLEM STATEMENT

Sustainable construction is an extremely relevant study field for the academic and business world alike. It is determined through several global factors which are steadily and undeniably transforming the globe and Egypt too; this includes fast demographic development, increasing urban development, resource scarcity, and speeding up carbon pollution and global warming, amongst many others. Egypt, like other developing countries, is highly susceptible to all of these potent forces that affect its future. While sustainable construction methods are broadly known mitigants to the previously mentioned global trends in the industrialized nations, they are largely neglected in the developing nation as a result of reductions in cost. A complete absence of knowledge outside and inside the government has aggravated this condition much further. There are no benefits – legal, administrative, or financial –to steer the different stakeholders in the sector towards environmentally friendly developments. It is apparent in the development and construction industry in which there is a rather strong separation of business interests between builders and investors. The developer promotes strategies of construction that are rapid, cheap, and simple. The investors are made to suffer the effects of construction choices taken by designers during the use-phase. Short-termism is often widespread in all construction industry groups. Inexpensive mixed-use buildings and residential solutions are recommended irrespective of the repayment time and long-standing financial advantages. For a nation experiencing an exponential rise in the population, urban growth, and greenhouse pollution, in addition to frequent energy shortages contributing to power outages, more research is needed about whether improvements to existing construction methods be able to accomplish sustainability that is enduring: addressing current demands and not damaging the reserves accessible for generations to come.

1.4 RESEARCH MOTIVATION

During the current point of economic growth and development in Egypt, this study is especially needed. Throughout the decade before the 2011 revolution, economic growth has been considerably fast. After overcoming the existing political turmoil, a much larger economic boost is anticipated in the coming years. Economic prosperity combined with exponential population growth would almost definitely contribute to an ongoing boost in the residential and business building market. Major consideration should be given for mitigating CO_2 emission of this development in order to prevent possibly devastating burden upon country's future generations. This toll most commonly may entail: (i) a rise in electricity scarcity resulting in a pandemic blackout situation, (ii) a rise in living costs for most Egyptians as a consequence of increased energy use and costs, and (iii) significant adverse health effects because of contamination of most essential resources like air, food, soil, and water.

1.5 OBJECTIVES AND SCOPE

The investigation is conducted with a goal to find existing sustainability methods used in the development and design of the world's high-rise mixed-use infrastructure and to identify concrete approaches that can contribute to more effective, environmentally safe, and space-efficient construction of mixed-use high-rise building in Egypt. It will aim to define the driving factors of carbon dioxide emissions relevant to the building phase, measure the increasing effect and recommend strategies to encourage more environmentally sustainable approaches where appropriate. Hence, this study would suggest a model for evaluating and examining, in Egypt, the CO_2 emission from high-rise building development–concentrating on mixed-use buildings so that it can: act as a roadmap to reduce CO_2 footprints in Egypt and lay the groundwork to replicate the study in other building sectors and regions. This would also develop sensitivity analytics to envision carbon emissions of buildings using various material mixes-primarily concrete, bricks, and steel. In this investigation, the evaluation emphasizes high-rise mixed-use buildings as a surrogate measure for the construction and design industry. There are numerous factors for choosing mixed-use High-rise buildings. First of all, high-rise mixed-use units are much less complicated and can, therefore, be used as a ground for other models to implement. Secondly, wanting to follow the Egyptian vision 2030, there seems to be a public interest in trying to expand to high-rise mixed-use buildings. Finally, this method helps readers and potential customers to reproduce the analysis on other high-rise building models by modifying the empirical hypotheses underlined in this report. This study will cover the design and development of key elements but will focus primarily on selecting, sourcing, and utilizing greener high-rise building practices to attain the most GHG cutbacks on the lifecycle assessment (LCA) basis. Architects, developers, contractors, and lawmakers are anticipated to take into account the findings of this investigation in establishing new environmentally friendly guidelines and standards for the industry in Egyptian construction. Another aim of this assessment is to gather and produce a detailed collection of data representing the different pollution generators during the building and lifespan of a house. Usually, this data is dispersed across different journals and sources that make it challenging for stakeholders of the industry to relate to or construct on it. The study attempts to overcome the stated limitation; thus, purposely comprehensive in chapter two of the literature review.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A substantial amount of academic as well as non-academic research is made accessible on all changing climate topics like green and sustainable development. Owing to its extremely apparent and drastic effect on the living standards of those around the globe, now the topic is at the leading edge of all industrial, educational, and political plans. This part of the study aims to discuss and outline some of the important trends and results in work relevant to sustainable building and climate change. Provided the existing prominence and widespread availability of the issue and the proliferation of inputs from a broad range of interest groups and stakeholders to the area, the analysis isn't confined to academic and scholarly study. Instead, the analysis mainly focused on input by a few of the top institutional officials of the world, policy and Decision-makers, and research institutes.

The detailed literature review shows many major results that firm foundation for the examination. The main purpose of this literature is to emphasize and examine the idea of embodied energy. Instead, the implementation of a more holistic and systematic lifecycle strategy is adopted to produce more effective conclusions and guidelines that can be easily evaluated and ultimately implemented to the Egyptian construction market–based on high-rise mixed-use buildings –with long-lasting, efficient, and financially-positive outcomes that will further improve the framework of the model in chapter 3.

2.2 GLOBAL TRENDS DEFINING THE ENVIRONMENT

A prominent consultancy for business strategy, Roland Berger, that guides large foreign public, industry, and service organizations in the main global economic centers with fifty offices across the globe. The variability in their global reach and the roles and clients they represent has driven the consultancy to release an article called "The Trend Compodium 2030" that describes the world's future in the coming 20 years (Berger, 2014).

Consequently, Roland Berger described several patterns that are transforming the world steadily and irreversibly in various groups. The shaping factors for the investigation are "Scarcity of Resources" and "Changing Demographics." (Berger, 2014). Moreover, in 2014, the United Nations Department of Economic and Social Affairs released a report titled

“World Urbanization Prospects." (United Nations, 2018). The released report aims to provide knowledge concerning common issues and potential policy proposals to UN member countries. (United Nations, 2018). Both reports explain the seven aspects in which the world is evolving:

2.2.1 GROWING WORLD POPULATION

It is projected that the global population will increase about 20 percent in the coming 20 years and reach about 8 billion in 2030. A significant increase in population would arise in developing nations, where the population increase rate in developed countries is seven times what they consume. By 2030 the population of the developing countries will reach 7 billion (Berger, 2014).

2.2.2 INCREASING CARBON FOOTPRINTS

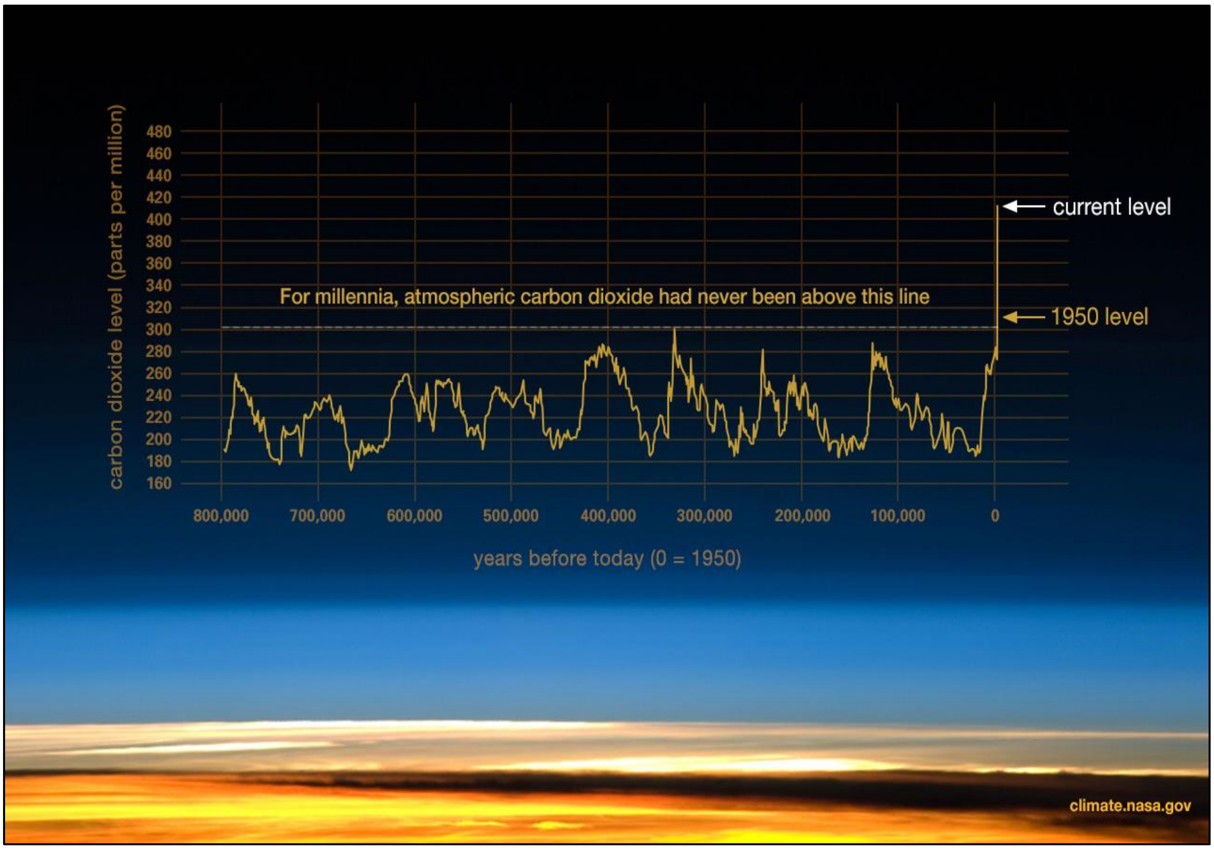


Figure 2-1: Global Carbon Emissions over time (NASA,2020).

In 2030 yearly CO_2 pollution due to the burning of oil, coal, and gas coal gas is going to rise about 18 percent. According to Berger, the CO_2 Emissions concentration in the atmosphere of the earth is 31% greater relative to the carbon emissions concentration prior to the Industrial Revolution (Berger, 2014). In addition to that, Joint Science Academies Statement released by the chief of Brazil, China, Canada, Germany, France, Russia, Italy, United States, Japan, and the United Kingdom, National Science Academies reported that CO_2 concentration rose to more than 375 parts/million (ppm) in 2005 from 280 (ppm) in 1750–as compared to all previous 420,000 years' concentrations (National Research Council, 2011).

2.2.3 GLOBAL WARMING

By 2030, the global temperature increase, on average, will be 0.5-1.5 ° C. It's correlated to an average rise in temperature of 0.5 degrees Celsius in the previous 20 years, with the temperature of land increasing almost at a double rate than temperatures of the ocean (Berger, 2014). World's sea surface and air temperatures have increased by 0.8 degrees Celsius since the 1900s, about 0.6 percent of which have happened as of 1980 (NRC, 2011). Moreover, per the Intergovernmental Panel on Climate Change (IPCC), the greatest driver to global warming is CO_2 footprint from the burning of fossil fuel, cement manufacturing, and land-use shifts, especially in deforestation due to its carbon properties (The Intergovernmental Panel on Climate Change, 2013).

The rise in temperatures globally results in:

- Rising sea levels and a shift in rainfall rates and trends (Vecchi, and Reichler, 2007);
- Subtropical deserts likely to expand (Vecchi, and Reichler, 2007);
- Ongoing melting of glacier, sea ice, and permafrost along with Arctic greatest temperature rise and Increased prevalent occurrences of radical climatic conditions (ex: heat waves, heavy rainfall, and droughts) (Vecchi, and Reichler, 2007);
- Acidification of the oceans and extinction of species because of temperature rise (Battisti and Naylor, 2009);

Globally, 59 percent of the population should reside by 2030 in Cities in developed nations; the number would be almost eighty-one percent relative to 55 percent in third-world countries (Berger, 2014). Europe, Latin America, and North America (73%, 80%, and 82% respectively) are by far the most metropolitan countries, while Asia and Africa are the lowest

(40% and 48% respectively). This continuing population rise and urban growth will bring 2.5 billion inhabitants to urban regions by 2050, with Africa and Asia (India, Nigeria, and China combined responsible for 37 percent of the rise) accounting for 90 percent of this rise (United Nations, 2018).

The rise in urban development would result in an environmental burden through:

- Higher heat generation and preservation resulting from the emergence of an increasingly urban and industrial area. This is a concept that is often called "urban heat islands." Throughout the cities, modern structures and roads absorb a significant part of the sun's energy leading to increased temperatures as compared to remote regions in which energy from the sun is absorbed by water evaporation from agriculture and soil. It is additionally to existing heat produced through cars, domestic or industrial cooling and heating in cities, and factories which are always 1-3 °C hotter as a consequence of this (Sanders, 2004). Figure 2-2 illustrates the urban population growth trend.
- Reducing soil moisture, leading to a decrease in CO_2 re-emissions (EPA, 2014).

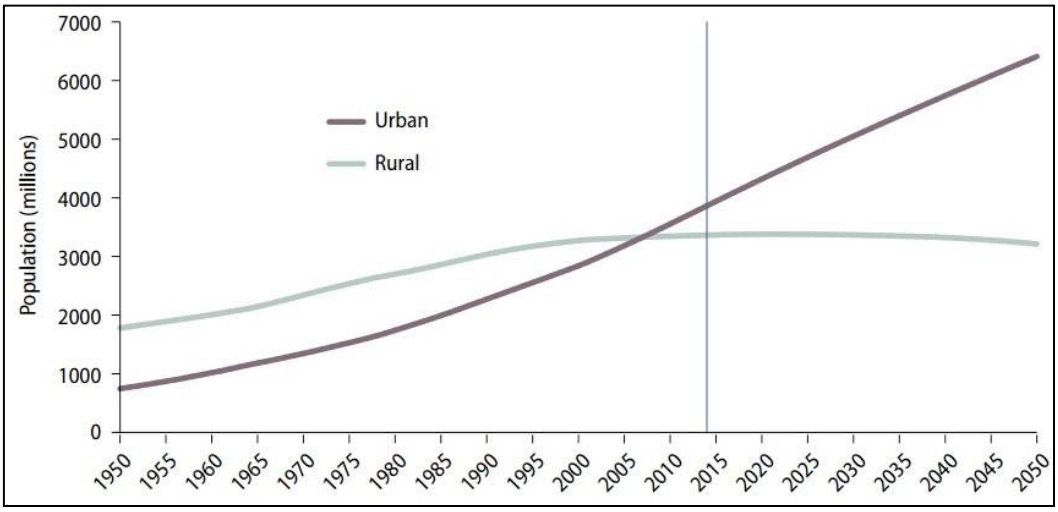


Figure 2-2 World's Urban & Rural Population (1950-2050) (United Nations, 2014)

2.2.4 AGEING WORLD POPULATION

By 2030, the global average age is expected to rise from 5 years to 35 years, primarily owing to increase life expectancy. The average age in developed nations will be forty-four years. The average age in developing nations is set to be 32 years (Berger, 2014).

2.2.5 BUILDING INDUSTRY

The Building Industry accounts for nearly 29 percent (about one-fifth) of CO_2 pollution globally, among which 6.4 percent are direct, and 12 percent are indirect heat and power generation (EPA, 2020). Figure 2-3 shows the yearly emission of GHG in every sector.

The United Nations Environmental Program (UNEP) in 2004 reported that one-third of GHG emissions (approximately equal to 8 million metric tons of CO_2) and forty percent of energy consumption are due to buildings. (United Nations, 2018).

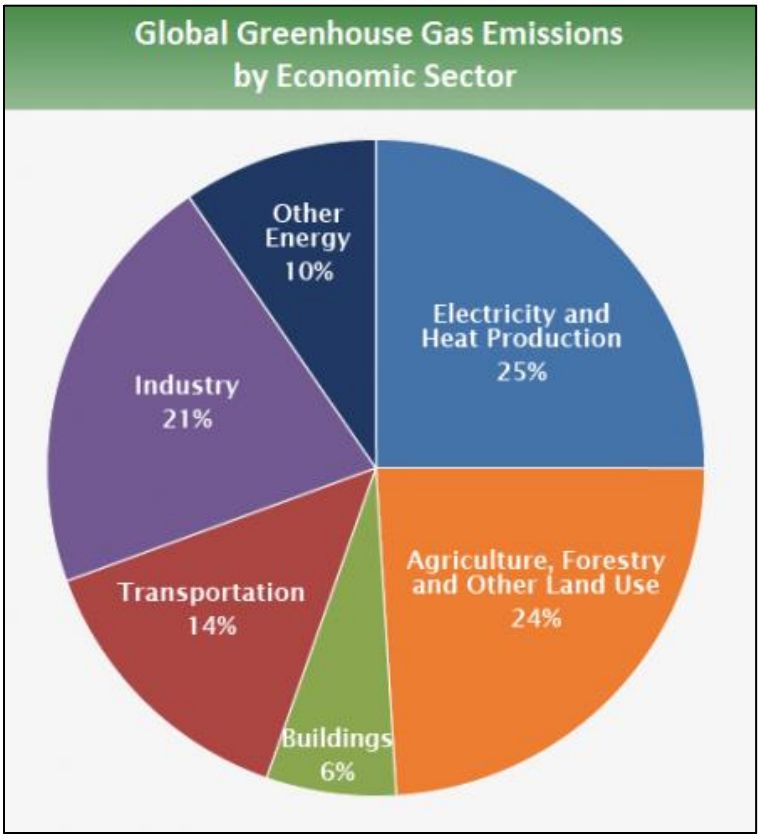


Figure 2-3: Annual Emission of Greenhous Gas Sector-wise (EPA, 2020)

UNEP evaluated the potential for carbon emissions reductions in different geographic regions and industries centered on the IPCC 2007 study and reached the conclusion that (i) carbon reduction from buildings significantly exceeds that from any other sector, like energy supply, industry, and/or agriculture, and (ii) with verified and commercially viable systems, energy usage in the existing and new buildings may be reduced approximately 80 percent with probable gross profit over the lifetime of the building (United Nations, 2018). Figure 2-4 illustrates that the biggest energy reduction potential in the construction industry.

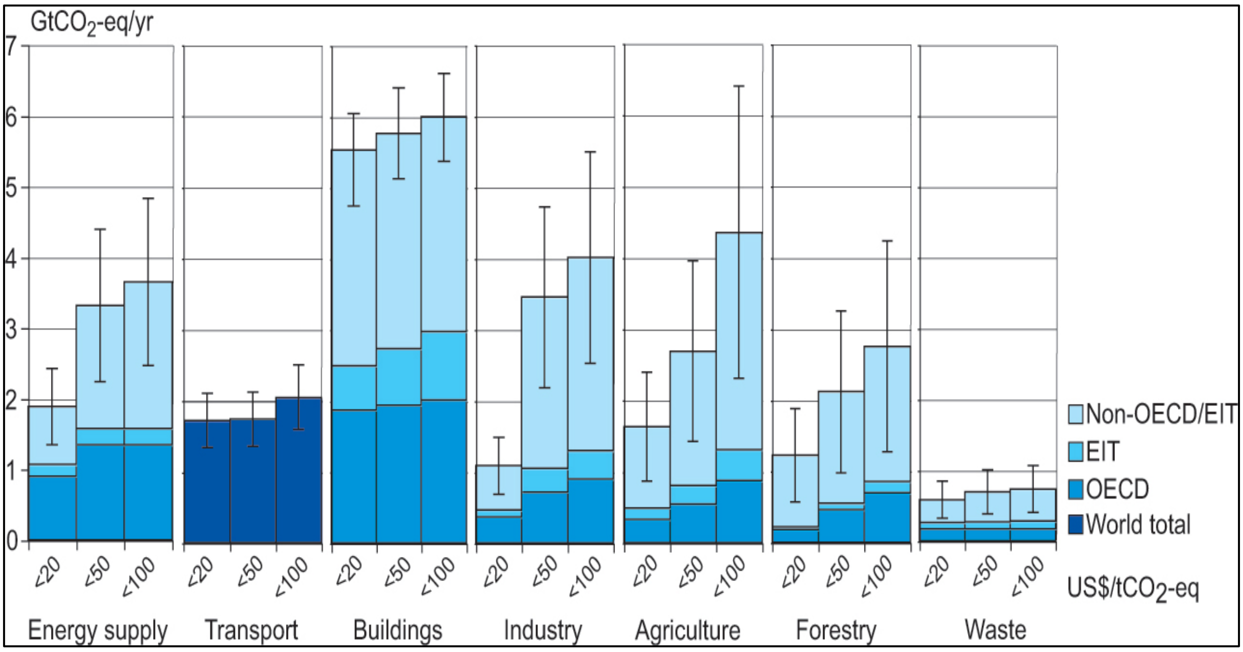


Figure 2-4 Possible Sector-wise Carbon Emissions Reductions (IPCC, 2007)

Consequently, UNEP advises evaluating CO_2 emissions of building structure through Life Cycle Approach (LCA). It revealed that more than eighty percent of GHG pollution arise during the use-phase of construction for ventilation, heating, cooling, electricity, machinery, etc. 10-20 percent energy utilized, a much lower percentage, is for capital spending needs (such as goods production, transport, building, repair, reconstruction, and demolition). It has been proved in Construction.com 's 2013 study "Life Cycle Assessment of Building Products," where its writer Peter J. Arsenault designs the building’s carbon pollution during its lifecycle. The author gives a concise and significant example of the carbon effect of buildings, in the long run, utilizing an LCA method and states that more than 75 percent of the emissions can be traced to continuing activities and that just 25 percent can be related to building materials and development. Thus, the study offers a persuasive reason for why prioritizing functional use-phase reduction programs is vitally necessary (Arsenault, 2013). Figure 2-5 illustrates an overview of standard energy consumption of buildings throughout their life cycle.

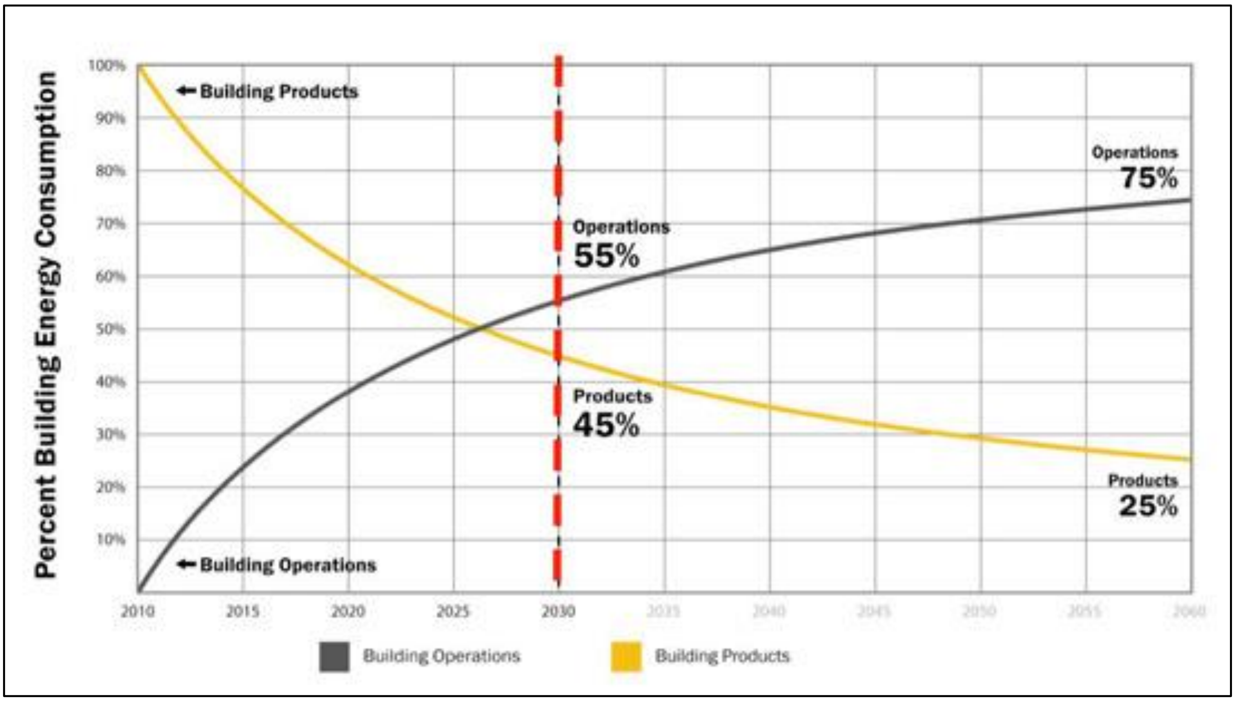


Figure 2-5: Overview of standard energy consumption of buildings throughout their life cycle (Arsenault, 2013)

2.2.6 MIXED-USE BUILDING'S CARBON FOOTPRINTS

Carbon footprints in housing or mixed-use buildings are attributable to raw material deployed during their development and indirectly because of the energy usage of its residential components throughout its use-phase. (Rodgers, 2018).

2.2.7 CARBON FOOTPRINT FACTORS IN CONSTRUCTION

CO_2 pollution factors throughout development are related to the materials used to create a residential or mixed-use structure. Their pollution differs according to the mode of processing (energy intensity) of each material. Any residential or mixed-use building's main building components are steel, bricks, and concrete (Rodgers, 2018).

2.2.7.1 CONCRETE

Production of concrete contributes to about 5 percent of GHG emissions worldwide. The principal components of concrete are water, cement, fine and coarse aggregates. Mostly the concrete CO_2 pollution is linked to the manufacturing of cement, which is responsible for around three percent of total CO_2 pollution worldwide (Rodgers, 2018).

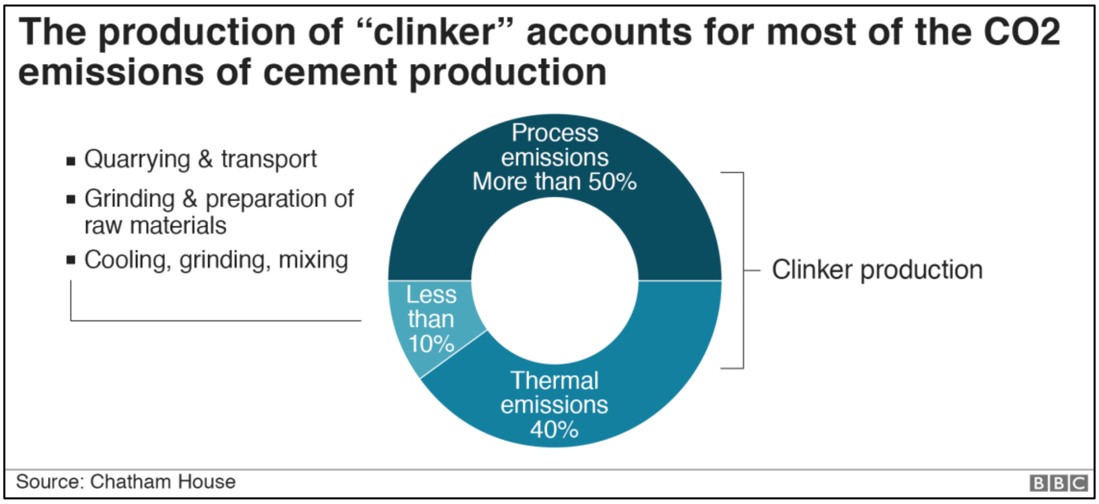


Figure 2-6: Concrete Industry's Emission of Carbon dioxide (Rodgers, 2018)

Cement manufacturing is a highly energy-intensive manufacturing process with high Carbon emission production. Cement Clinker production is the major element that produces CO_2 emissions within Cement Manufacturing, as illustrated in Figure 2-6 (Rodgers, 2018).

However, Water, fine and coarse aggregates, as well as other materials, make 90 percent, by weight, of the concrete mix design, but the process of crushing of the stones, excavating the gravel and sand, mixing all the materials together in the concrete plant and transferring it to the building location needs just a fraction of the energy used for Cement Production, and thus it generates a small amount of Carbon dioxide. The concentration of CO_2 encapsulated in concrete is, because of the quantity of cement (Rodgers, 2018).

PRODUCTION OF CEMENT

The manufacturing of cement is a procedure requiring intensive energy and is a key cause of carbon footprint. As 1 ton of Portland cement manufactured produces roughly about 820 kg of CO_2. Figure 2-7 and Figure 2-8 illustrate the production of cement. Carbon pollution from fossil fuel burning and cement grinding contribute 46 percent, whereas 54 percent are because of limestone calcination in the raw mix (Vanderborg et al., 2016).

The method includes numerous phases, which include mining, grinding, heating, and distribution, which are outlined under:

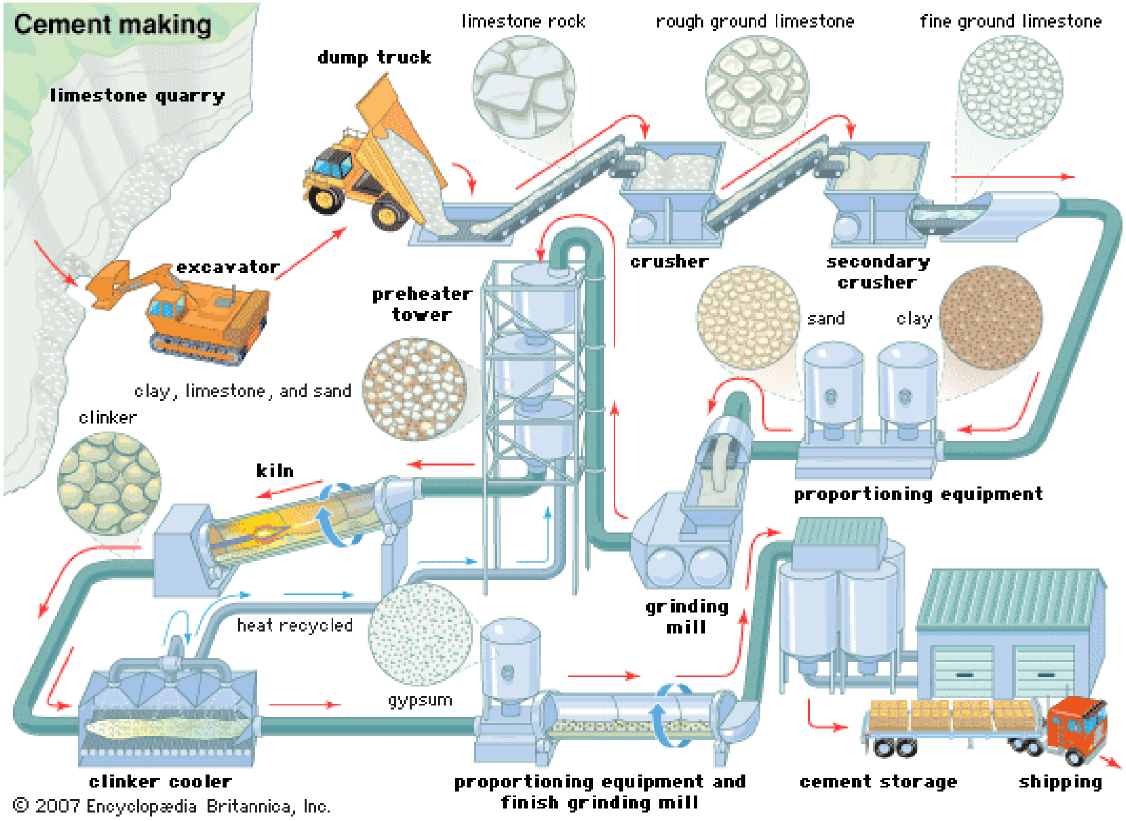


Figure 2-7: Efficient Cement Production Infinity for Cement Equipment FOR (CEMENT EQUIPMENT, 2018)

1. Preparation of Raw Material – limestone, clay, and chalk are the raw materials used. Small amounts of CO_2 are generated due to the raw material extraction and their transport to the cement plant (Rodgers, 2018).

2. Grinding of Limestone Rocks – in primary and secondary crushers, limestone is grinded into small fragments (Lafarge, 2018).

3. Blending and Fine Grinding – to obtain an even production of cement, raw materials are perfectly shaped. Then, the raw materials are prepared for fine grinding, a critical step, as their standardization and fineness will aid to minimize the heat consumption in clinkering and conserve resources having lower energy consumption (Lafarge, 2018). ‘Raw meal’ are raw materials that are perfectly grinded (Lafarge, 2018). Two processes are required for fine grinding: Dry and Wet methods in which the dry method is considered to be without water, and the wet method, the water is combined with the raw material creating a cement slurry (Lafarge, 2018).

4. Clinkering is the process where dry or wet mixtures are then powered in an angled rotary kiln. Then, raw materials move down the burning flame areas in which the temperatures can touch almost 2000 degrees Celsius. This heat induces the raw meal to alter chemically and physically, which converts it into a substance named clinker, and to conserve energy, there is a cooler at the kiln end in which clinker is chilled through the air, and the heat collected from this cooling cycle is recirculated into the kiln (PSA, 2015).

   The vertical preheaters cyclones, in which, before reaching the rotary kiln, raw meal moves down. When they pass through the preheaters, they interact with the exhaust gasses of the hot kiln, and as a consequence, the raw meal is preheated ahead of reaching the kiln, and hence the required chemical reaction happens quickly and effectively. On the base of the preheater, calciner is a combustion chamber allowing for smaller rotary kilns and the usage of renewable fuels of reduced quality (PSA, 2015). The preheaters are incorporated to preserve and use energy, thus saving energy.

   To drain water from the raw wet meal as additional energy is needed, the rotary kilns need more fuel and are bigger for a wet mix relative to the dry mix ones. Process kilns for a raw wet meal have a diameter of 8 meters, 230 meters in length, and manufacture 1 ton of cement from about 230 kg of coal. On the other hand, standard-sized dry process kilns are 50 to 100 meters long, have a diameter of 3-10 meters, and manufacture 1 ton of cement from about 120 kg of coal (AGICO Group, 2019). This means more energy is consumed from cement manufactured through the wet process, hence more CO_2 pollution as compared to the dry process. Thus, the manufacturing of cement must be accomplished using the dry process to save energy.

5. Final Grinding – gypsum is added to the cooled clinker, an important element for controlling concrete setting times. It is also possible to add slag and fly ash into the mixture (Lafarge, 2018). Cement grinding at the final phase is accomplished by primary crushers and secondary crushers (Lafarge, 2018).

6. Packing and Transporting – Cement is filled into bags and fully prepared to be shipped.

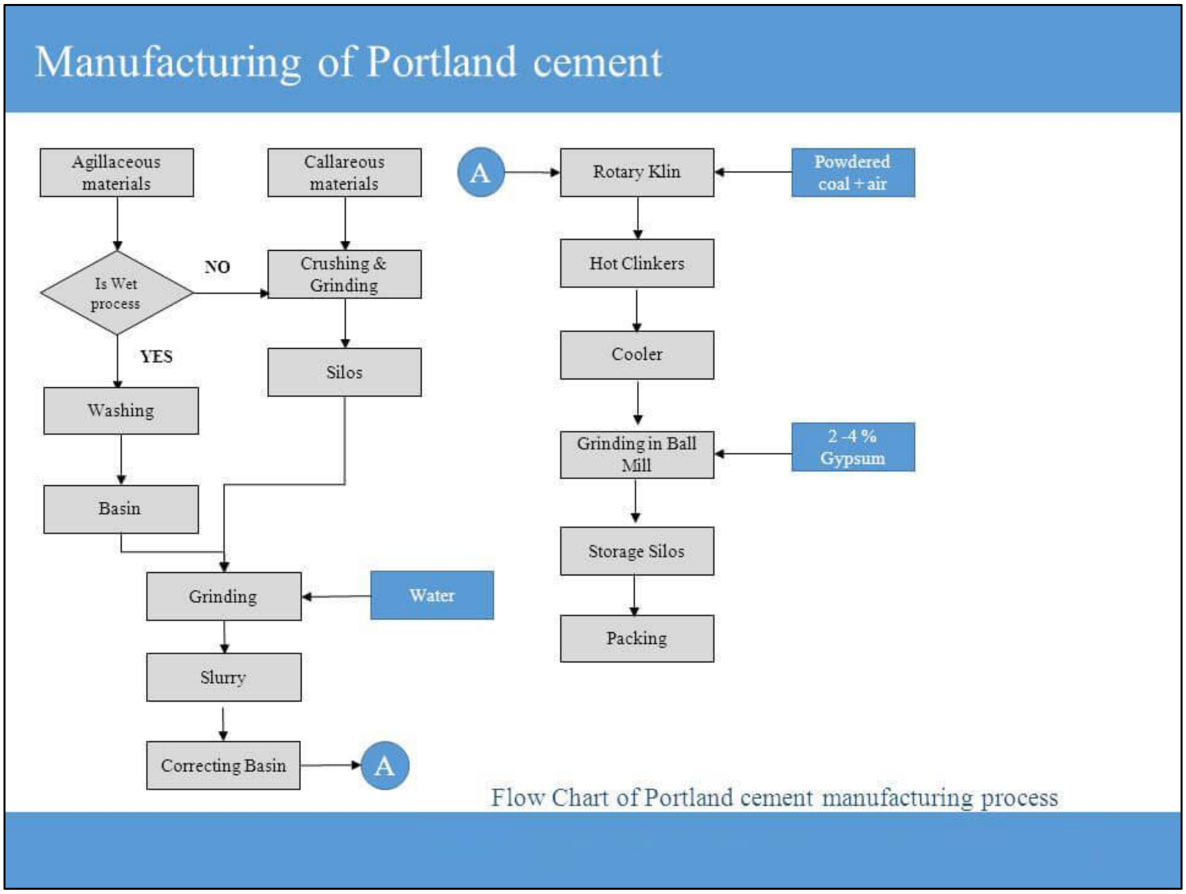


Figure 2-8: Flow Chart for Cement Manufacturing (AGICO Group, 2019).

SUSTAINABLE CONCRETE

The manufacturing of concrete that is eco-sustainable has great significance as it will help to build an eco-friendlier environment. It will involve a few facets to be taken from manufacturing the components of the concrete to modifications in the mixture. Lower emissions concrete requires:

1. Improvements in the efficiency of energy: making a manufacturing cycle that has efficient energy would prevent a great deal of CO_2 emissions from electricity usage and fuel. It would aid in reducing the CO_2 produced from the manufacturing of cement through using the right tool and procedure for the production of cement (e.g., use a preheater and dry processing technique for cement production cycle). In addition, the use of energy-efficient equipment will make a significant difference throughout the construction processes (Worrell, 2001).

2. Substitution of Fuel (High-Carbon): The use of fuels with low-carbon will reduce carbon emissions over the long cycle (Worrell, 2001). Therefore, using natural gas or waste instead of coal as fuel in cement plants can be accomplished (medical waste, used oil, and tires) (World Bank, 2016).

3. Substituting Clinker: using by-products from the industry such as pozzolanic materials, fly ash, or blast furnace slag and mixing it to a clinker for the production of blended cement. Its setting period is long and is stronger as compared to Portland Cement (Worrell, 2001). Mixed types of cement need fewer clinkers and will therefore reduce CO_2 footprint.

4. Substituting Cement: Substituting a fraction of cement in the concrete mix with mineral admixtures like fly ash, slag, or silica fume. Thus, decreasing the ratio of cement required in a mixture and, subsequently, the need for cement production.

    - When utilizing admixtures that are water-reducing in a concrete blend, cement is lowered by as much as 10 percent with an equally concrete intensity (Rodgers, 2018).

    - The by-product from the production of ferrosilicon or silicon is silica fume, in which, during the manufacturing process, the fume's compressed through filters in the outlet of escaping gases. It has a large silicon dioxide content, and when combined along with concrete, silica fume reacts with lime boosting the effectiveness of concrete. Over 12,000 tons of silica fumes are released by Egypt annually (Khedr and Abou-Zeid, 1994).

    - Combustion of pulverized coal in the electrical power plants produces the by-product fly ash. Flue gases transport the residue that has not been burned and gathered by electrostatic separators. The residue that has not been burned stays at the furnace's end. It is called bottom ash. Fly ash is a pozzolanic substance formed from finely broken alumino-silicates with differing concentrations of calcium. When it is combined with water and cement, it reacts with the calcium hydroxide produced from cement hydration to create calcium-aluminate hydrates and calcium-silicate hydrates (C-S-H). Besides that, such reactions are advantageous for the concrete, as they improve their long-term resilience and decrease their absorption. Thus, ending with a concrete that is strong (Nochaiya et al., 2010).

5. Innovative Cement: geopolymer concrete generate about 9 percent less CO_2 as compared to Ordinary Portland concrete. Geopolymer Concrete is composed of alumino-silicates instead of calcium oxide, in which the silicates are released through industrial waste products. This can be mixed with plastic fibers or steel, where geopolymer concrete with fiber-reinforced is much more acid, sulfate, fire, and corrosion-resistant.
6. Innovative aggregates: for new construction, employing crushed concrete as concrete aggregates (World Bank, 2016).

2.2.7.2 STEEL

A key element utilized in high-rise buildings is steel, which is the strongest element of every concrete framework. The strength/weight percentage of steel is good, implying the weight of steel needed to be used remains typically lesser as compared to other material substitutes without damaging its strength. As compared to other materials, it is robust, permitting for flexible and wider span models (Tata, 2019).

The building sector is the biggest steel user, with around 50% of the overall steel use globally. However, the steel sector is an industry that requires intensive energy, responsible for around 7 percent of overall CO_2 pollution globally. Because of the predicted population growth, and subsequently, steel demand, the volume of CO_2 released would be a key problem. Steel demand has been projected to rise 1.5 times by 2050, and as a consequence, carbon pollution would rise at the same rate (World Steel Association, 2012).

MANUFACTURING STEEL

Two manufacturing ways for steel are implemented; below are two ways for the production of steel:

1. Blast Furnace with basic oxygen furnace production (BOF):

Through the production process, the blast furnace pig iron is generated with iron ore and coke. Then, in a basic oxygen furnace, steel is produced in which oxygen is pumped via the hot metal (EVRAZ, 2016).

Thus, to generate 1 ton of crude steel, it needs coal - 800 kg, iron-ore - 1400 kg, recycled steel - 120 kg, and limestone - 300 kg (World Steel Association, 2012). In addition to that, an average of 1 ton of steel produced by this method produces an average of 2 tons of Carbon emissions (EVRAZ, 2016). A method termed 'reduction' takes place in the blast furnace as carbon emissions are generated from metal extraction by iron ore. The process is shown in Figure 2-9.

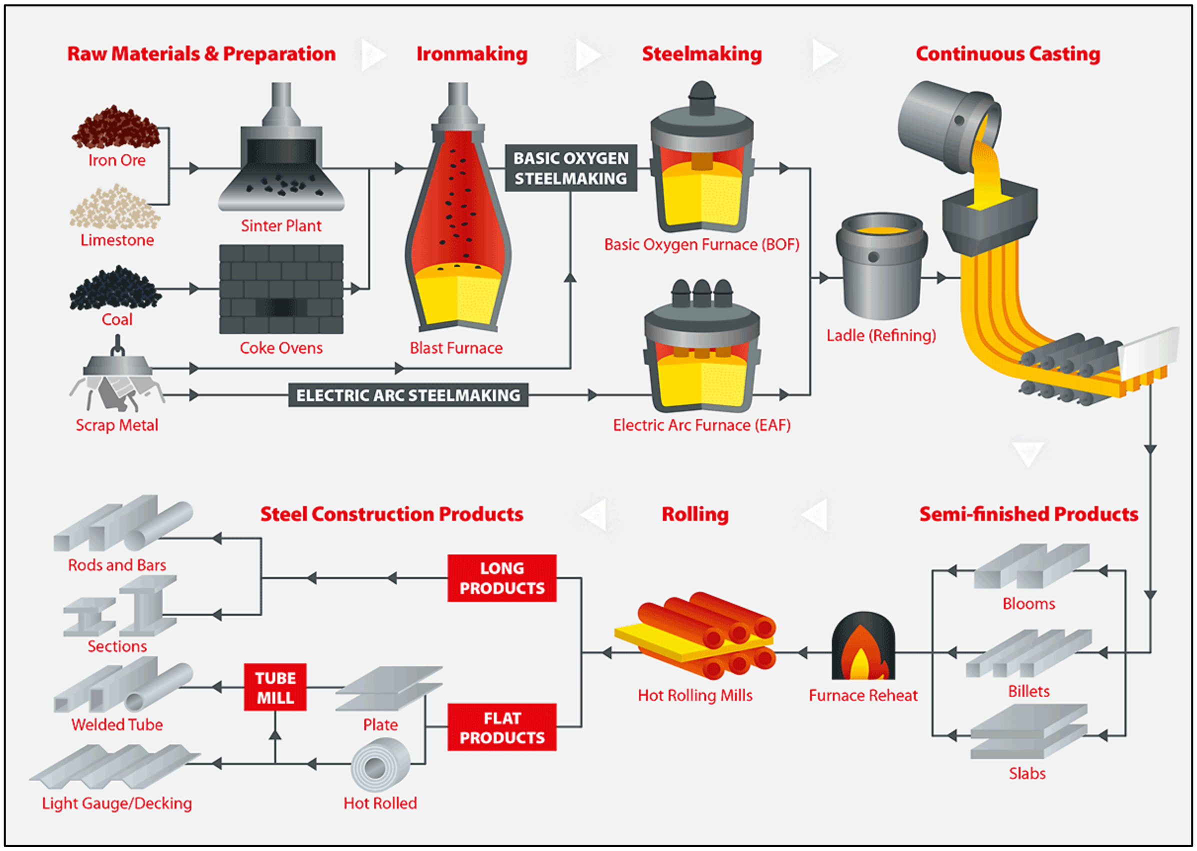


Figure 2-9: Basic Oxygen Furnace Method and Electric Arc Furnace Method (New Steel Construction, 2017).

2. Electric Arc Furnace production (EAF):

Through this production process, iron generated is turned to molten form and transformed to steel through highly powered electric arcs created among an anode and a cathode. The iron may be generated from directly reduced iron in solid-state or scrap (New Steel Construction, 2017).

Hence, to generate 1 ton of crude steel, this route typically takes limestone - 64 kilograms, coal - 16 kilograms, and recycled steel - 880 kilograms (World Steel Association, 2012). The optimal usage rate is 350 kWh, which would result in yearly energy efficiency (New Steel Construction, 2017). In addition to that, an average of 1 ton of steel produced by this method produces an average of 0.441 tons of Carbon emissions which makes the Electric Arc Furnace Route is considered to be more sustainable (EVRAZ, 2016). A method termed 'reduction' takes place in the electric arc furnace as carbon emissions are generated indirectly from electricity used (New Steel Construction, 2017). An electric arc furnace’s plan view and section is illustrated in Figure 2-9.

SUSTAINABLE STEEL

As discussed above, electrical Blast furnace methods are more sustainable, producing 61% less CO_2 emissions than traditional Oxygen Blast furnace manufacturing methods. However, there are some measures that can be taken to minimize the environmental harms that are caused by the regular Oxygen Blast furnace in the manufacturing of steel. Such measures would help preserve the environment, and so it is really necessary to learn innovative approaches and implement them. Lower emissions steel would require:

1. Improvement of Energy Efficiency: manufacturing procedure that is energy-efficient would prevent huge volumes of CO_2 emissions (World Steel Organization, 2018).
2. Greater reuse and recycling frequency of Steel: without destroying its properties, steel has the ability to be recycled and reused. Reductions in CO_2 pollution from the reuse of buildings are between 1 to 1.5 kg of CO_2 per kg of steel produced (World Steel Association, 2018). Illustrated in Figure 2-10 illustrates steel's infinite lifecycle.
3. Greater Recycling and Use of By-Products from Steel: The by-products formed from steel production can be recycled or offered to different sectors, thereby avoiding landfill waste, lowering CO_2 pollution, and helping to protect natural resources. The following are the major by-products: sludge, Slag, dust, and process gasses.

A. Slag can reduce cement prices (World Steel Association, 2018). The two kinds of slags are:
   (i) Air-cooled slags that are rigid and thick; ideal to be used as construction aggregates, or used as insulation in mineral wool and roofing, road surfaces and bases, ready-mixed concrete
   (ii) Granulated slags are tiny glass particles that are used for producing cemented material (World Steel Association, 2018).

B. For decreasing the need to generate electricity externally, gasses generated can be utilized internally (World Steel Association, 2012).

C. Sludge and dust eliminated through the gasses consist of iron that may be reused during steel production (World Steel Organization, 2018).

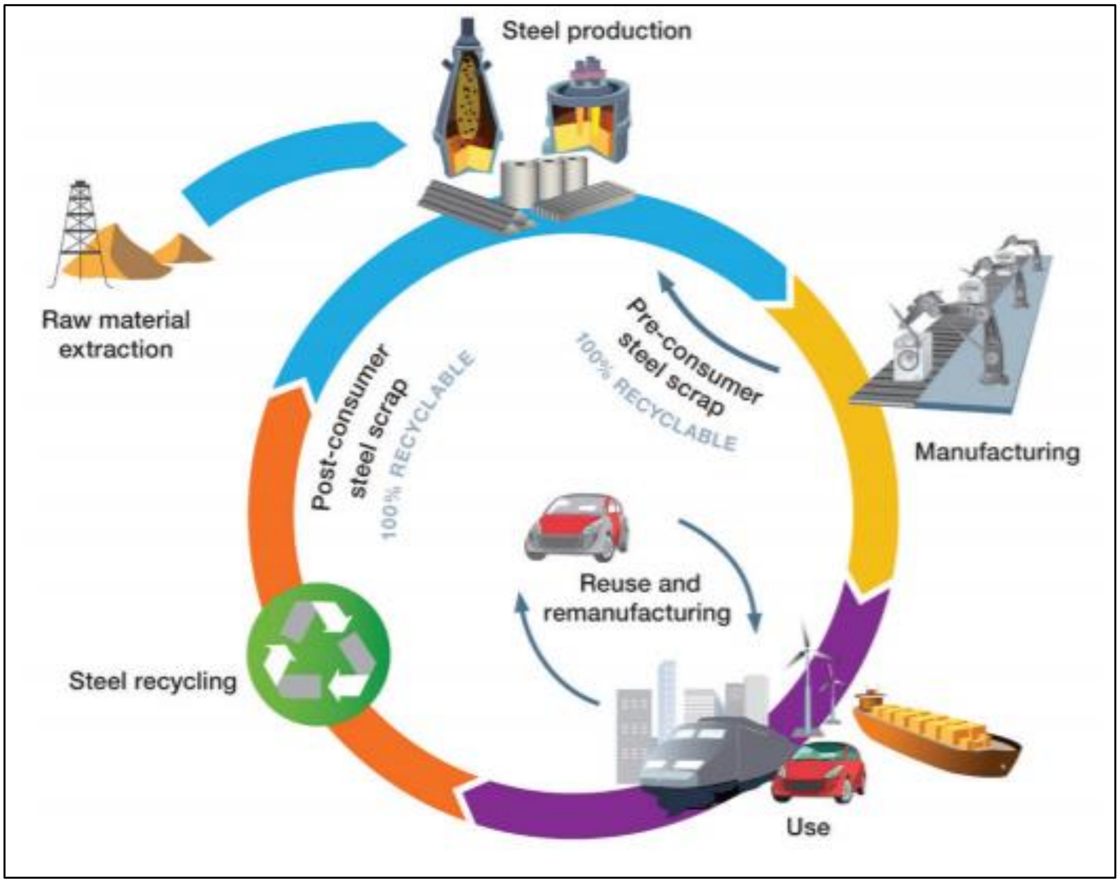


Figure 2-10: Cycle of Steel (World Steel Association, 2018)

2.2.7.3 BRICKS

Bricks are flexible, robust construction material with outstanding efficiency throughout the life cycle. They need minimal maintenance and are recyclable, which contributes to their characteristic of energy efficiency (Brick Development Association, 2020).

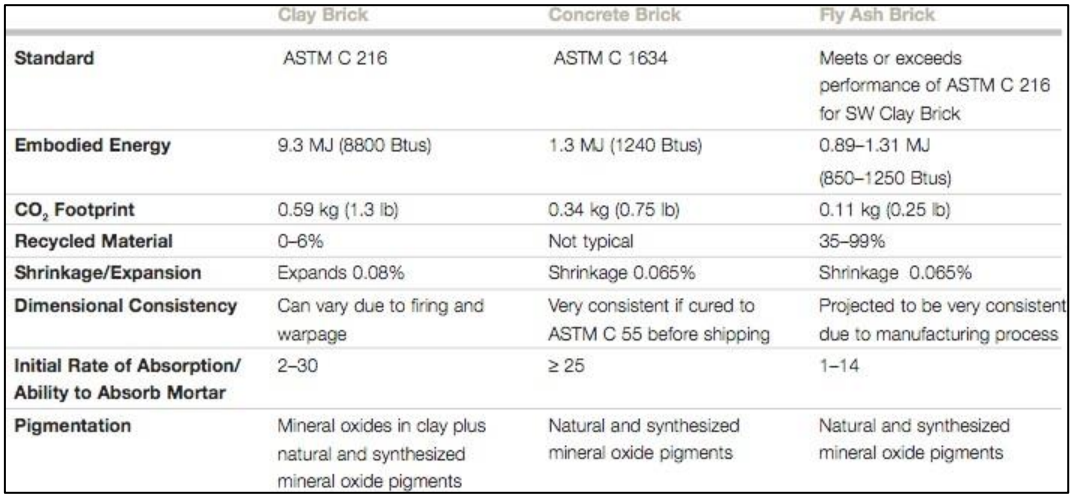
Clay bricks are the commonly used and conventional kind, but they require intensive energy along with the greatest carbon dioxide pollution and embodied energy (Brick Development Association, 2020). The effort in finding solutions in the brick industry that are sustainable has led to the manufacturing of existing bricks with improvements and production of new bricks as well.

Bricks are divided into the following two categories: fired and non-fired. Clay bricks fall in the fire bricks category, whereas the non-fired ones are concrete and fly ash bricks. The issue of the fired bricks occurs in the firing phase, the red-hot kilns release fuel in huge volumes and are the major source of CO_2 pollution, and the kilns work all the time even if they have not reached the maximum capacity (Brick Development Association, 2020). Hence, to manufacture more sustainable conventional clay bricks, numerous sustainable methods can be used. This comprises:

- Alternative Fuels – It is possible to use petroleum coke oil refining by-products or natural gas collected from landfills, but both produce almost an equal volume of CO_2 , and thus pollution will stay elevated (Brick Development Association, 2020).
- Materials: recycled – Recycling usually has no significant effect on the use of energy and CO_2 footprint (Brick Development Association, 2020).
- Reduce Surface Area: reducing deep frogs or coring is used in decreasing the quantity of clay/brick. The recessed panels in the brick's bearing surface are called frogs, and coring is holes in the segment, which decreases the surface area by 25 percent. Deep frogs thus need more mortar and hence adversely affect their environmental advantage. In fact, the number of bricks made will remain constant, and the bricks also have a similar capacity (Brick Development Association, 2020).
- Non-Clay Bricks – recycled glass, ceramic scrap, recycled iron oxides, and processed sewage wastes are the materials found in the bricks that are 100 percent recycled. Such bricks are ablaze at clay brick plants. Although they are recycled

products, their carbon footprint and embodied energy are identical to traditional fired clay bricks. The temperature of the kiln and firing period was 33 percent and 5 percent, respectively, which is less than normal clay bricks (Brick Development Association, 2020).

Non-fired bricks remove the issue of firing, therefore, decreasing the emissions, hence making bricks with fewer embodied energy and CO_2 footprint. Concrete bricks contain the standard concrete materials and have the same density and strength as the fired clay bricks, although the issue with non-fired bricks is in the manufacturing of cement, which leads to the greatest CO_2 pollution. Fly ash bricks are manufactured from recycled fly ash from coal-fired power plants) and recycled material, which hit 15 to 20 percent of fired clay brick emissions (Brick Development Association, 2020). conventional fired clay bricks with fly ash bricks and non-fired concrete are compared in figure 2-11.



	Clay Brick	Concrete Brick	Fly Ash Brick
Standard	ASTM C 216	ASTM C 1634	Meets or exceeds performance of ASTM C 216 for SW Clay Brick
Embodied Energy	9.3 MJ (8800 Btus)	1.3 MJ (1240 Btus)	0.89–1.31 MJ (850–1250 Btus)
CO_2 Footprint	0.59 kg (1.3 lb)	0.34 kg (0.75 lb)	0.11 kg (0.25 lb)
Recycled Material	0–6%	Not typical	35–99%
Shrinkage/Expansion	Expands 0.08%	Shrinkage 0.065%	Shrinkage 0.065%
Dimensional Consistency	Can vary due to firing and warpage	Very consistent if cured to ASTM C 55 before shipping	Projected to be very consistent due to manufacturing process
Initial Rate of Absorption/ Ability to Absorb Mortar	2–30	≥ 25	1–14
Pigmentation	Mineral oxides in clay plus natural and synthesized mineral oxide pigments	Natural and synthesized mineral oxide pigments	Natural and synthesized mineral oxide pigments

Figure 2-11: Comparison of Types of Brick (Chusid et al., 2009).

2.2.8 CARBON EMISSIONS FACTORS IN BUILDING'S OPERATIONAL PHASE

As stated earlier, CO_2 pollution in the use-phase of a domestic or mixed-use building is mainly generated from the intensive usage of electricity. As stated earlier, carbon pollution during the use-phase of a domestic or mixed-use building is mainly generated from the intensive usage of electricity. Hence, efficient electricity consumption will prevent a huge amount of carbon pollution and much energy too. This part highlights and discusses the driving factors of CO_2 pollution in-depth along with likely emission reductions. The following are the factors: (water heaters, air conditioners, Lighting).

2.2.8.1 LIGHTING

Lighting is responsible for about 6 % of CO_2 emission globally, which is equal to 1,900 million tons of CO_2 ($MTCO_2$) per annum (Climate Group, 2020). The unit used to measure light is lumens (lm). It is the overall amount of visible light produced from a source. Luminous efficacy stated in lumens/watt (lm / W) is known as light's efficiency (Alonso, 2007).

It is important to select the most effective form of lighting as it will determine the amount of pollution produced over its lifespan, so optimizing the reductions will undoubtedly lead to building an energy-efficient house. The three light bulbs types are incandescent light, compact fluorescent light (CFL), and light-emitting diodes (LED). Though, carbon pollution can be lowered by 50-70 percent by utilizing LED lamps and smart controls (Climate Group, 2020).

INCANDESCENT LIGHT

When a filament lights as it is heated at extreme temperatures as an electric current move in it, incandescent light is generated. This filament is covered inside a quartz bulb or glass, which is filled with a noble gas in order to avoid oxidation. Unlike other forms of electrical lighting, incandescent bulbs are the least efficient, since it transforms 95% of the electricity into heat and only five percent of it is transformed into visible light. The luminous strength of incandescent light is seventeen lm/W (Energy Rating, 2020). Its inefficiency occurs not just in the total electricity usage but in its lifespan too. It has the smallest lifespan, which is about 1,000 hours for light bulbs at the office, home, or at shops. Incandescent light has a small initial cost than the cost of energy (NOPEC, 2019). An incandescent light bulb is illustrated in Figure 2-12.

Figure 2-12: Incandescent Light Bulb (Energy Star, 2017)

COMPACT FLUORESCENT LIGHT (CFL)

A CFL is a mercury-vapor, low-pressure, gas-discharge bulb that produces visible light using fluorescence. Light is emitted when the mercury vapor that produces ultraviolet light is excited by an electric current, which produces a coating of glowing phosphorous (Energy Star, n.d.b). As compared to incandescent lamps, it is more efficient, with a lifespan of 10,000 hours and luminous efficacy of 60 lm/W (Energy Rating, 2020). CFL are costly as compared to incandescent lamps, but with the same quantity of light, they consume less electricity, which is why they last longer and therefore offset their great initial price (Energy Rating, 2020). A CFL bulb is portrayed in Figure 2-13.

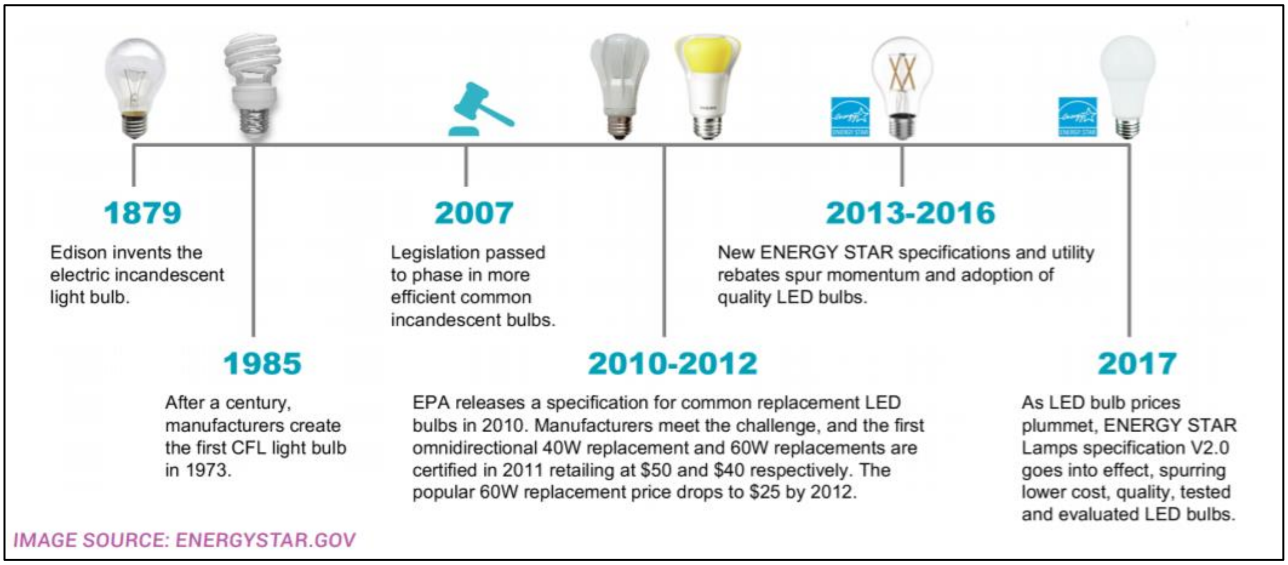
Figure 2-13: Compact Fluorescent Light (CFL) Bulb (Energy Star, 2017)

LIGHT-EMITTING DIODE (LED)

A LED is a light source with a two-lead semiconductor. It produces energy in the form of light as the voltage is applied to the lead (NOPEC, 2019). It has a luminous efficiency of 100 lm/W and 30,000 hours of lifespan (Energy Rating, 2020). Light-emitting diode has the best performance among all forms of electrical lighting. These are the highly-priced form of illumination, but their efficient electricity usage and long-life offset this expense. A LED bulb is illustrated in Figure 2-14.

Figure 2-14: LED Light Bulb (Energy Star, 2017)

The most efficient type of lighting is LEDs. They are predicted to be the emerging lighting in the coming years. Based on the study from Energy star and Energy rating the solid-state light-emitting diodes will dominate the industry by 2020 (Energy Rating, 2020) and enable both the compact fluorescent (CFL) and the incandescent bulbs to be eliminated (Energy Star, 2017). Figure 2-15 illustrates the Light bulbs evolution.


1879
Edison invents the electric incandescent light bulb.

1985
After a century, manufacturers create the first CFL light bulb in 1973.

2007
Legislation passed to phase in more efficient common incandescent bulbs.

2010-2012
EPA releases a specification for common replacement LED bulbs in 2010. Manufacturers meet the challenge, and the first omnidirectional 40W replacement and 60W replacements are certified in 2011 retailing at $50 and $40 respectively. The popular 60W replacement price drops to $25 by 2012.

2013-2016
New ENERGY STAR specifications and utility rebates spur momentum and adoption of quality LED bulbs.

2017
As LED bulb prices plummet, ENERGY STAR Lamps specification V2.0 goes into effect, spurring lower cost, quality, tested and evaluated LED bulbs.

IMAGE SOURCE: ENERGYSTAR.GOV

Figure 2-15: Light Bulbs Evolution (Energy Star, 2017)

2.2.8.2 AIR CONDITIONERS

There are three components of an air conditioner: a cooling part called an evaporator, a compressor pump, and a hot coil called a condenser. The cooling part (evaporator) transfers cooler air in the room, whereas the warm air is released outside by the condenser. Refrigerant is transferred between the condenser and the evaporator by the compressor pump in order to change it from liquid to gas to transfer warmer and cooler air (Engineering Pro Guides, 2019). The refrigerant process for ACs displayed in Figure 2-16.

the environment can be saved or damaged depending upon the refrigerant used. It is very important to carefully choose a refrigerant, as it can end up causing global warming and ozone depletion (Emerson Climate Technologies, 2015).

Fifteen miles beyond the surface of the Earth is a reactive type of oxygen known as the ozone layer. This layer is important for life on earth as it stops the sun’s dangerous UV rays from entering Earth. Hence, its depletion can disrupt the standard of living in humans, wildlife, plants, and marine life. Refrigerant's chlorine has been shown to make a significant contribution to the ozone layer’s depletion, most of which is due to hydrochlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs) and hence refrigerants that are chlorine-free should, therefore, be utilized as a substitute to minimize more damage, like hydrofluorocarbons (HFCs) (Emerson Climate Technologies, 2015).

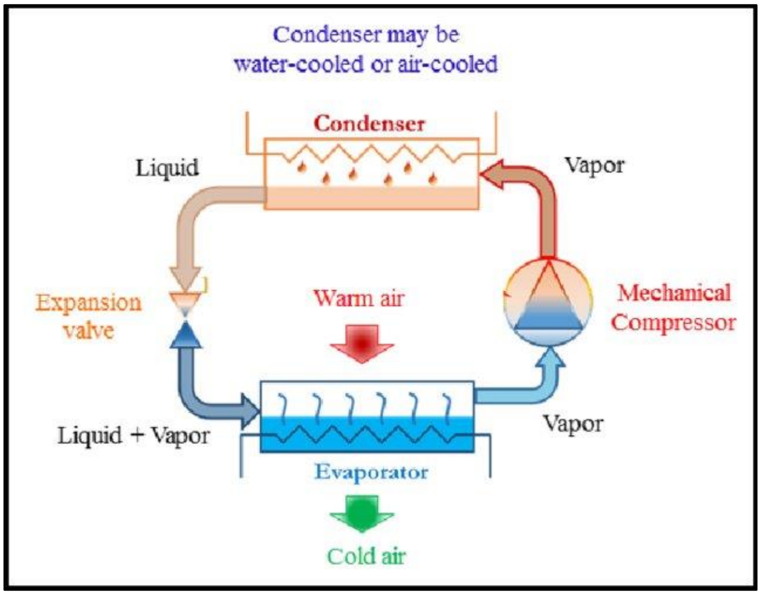


Figure 2-16: Refrigerant Cycle (Pal et al., 2018)

Climate change is the consequence of human activity producing Greenhouse gases; refrigerants are a GHG that lead to an elevated effect of heating. HFCs are projected to add about three percent of Greenhouse gas emissions by 2050 (Emerson Climate Technologies, 2015).

The calculation of the total equivalent warming impact is based equally on direct and indirect Air conditioning system emissions:

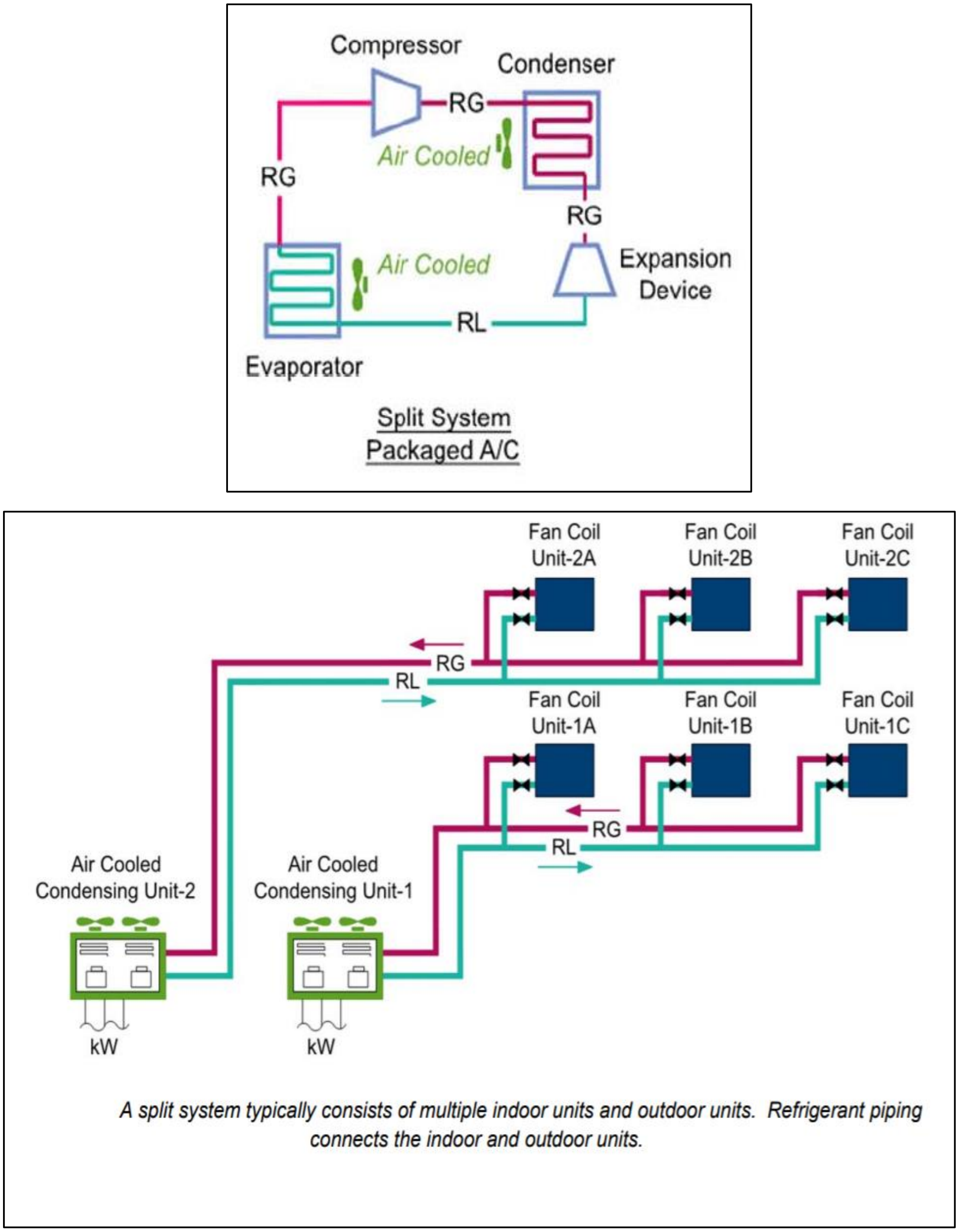
- Direct Air conditioning system emissions: the refrigerant's direct impact as it releases into the air is measured by Global Warming Potential (GWP). It happens when refrigerants are incorrectly fitted in the refrigerant units that cause leakage or fail to recycle the fluids from the refrigerant during the end of its life. Either of these conditions would result in refrigerant emissions contributing to about 20% of overall emissions (United Nations Climate Change, n.d.). Emissions into the air can be reduced by early detection of leakage (Emerson Climate Technologies, 2015).

- Indirect Air conditioning system emissions: they are dependent on the efficiency of a machine; its energy efficiency and power source are taken into account. The smaller the equipment's efficiency, the more electric power it will use, resulting in greater CO_2 emissions (Emerson Climate Technologies, 2015). These emissions contribute about 80 percent of total emissions (United Nations Climate Change, n.d.). The primary goal is to focus on the refrigeration system’s quality because of indirect emissions' greater contribution to Carbon discharges.

The TEWI should be computed when choosing among various refrigerant alternatives. TEWI is the total of a refrigerant's direct (refrigerant) and indirect (energy) emissions, considering the power consumption/efficiency of the system and the refrigerant emissions. This comparative analysis would give a fair assessment of the impact on climate change. Due to its low GWP and Carbon footprint as opposed to CFC and HCFC refrigerants, HFCs were considered the best choice for refrigerants. A refrigerant, besides the TEWI, must have the following: (i) be stable chemically, (ii) accepted in the environment, (iii) not toxic, and (iv) not flammable (Emerson Climate Technologies, 2015). The sustainable usage of refrigerants is by placing them in a piece of ingenious equipment, ensuring that the system is extremely proficient, recovering, and recycling them in the final stage of its lifespan (Emerson Climate Technologies, 2015). Below the different types of AC systems will be discussed:

SPLIT AC SYSTEM

The system depends on two units which are the indoor fan coil unit and the outdoor air-cooled condenser units. Both units are connected by sets of refrigerant piping. The Refrigerant piping is divided into supply and return lines. The supply line has refrigerant liquid (RL) which is delivered to the fan coil unit, becoming a saturated cooler liquid which then evaporates in the evaporator coils cooling the air blown over it. Besides that, the return line has a hot refrigerant gas (RG) which is delivered back to the condensing unit (condensing Fans and coils), which compresses and cools the gas returning it back to a liquid state (RL). The cycle then iterates itself several times, cooling air through the operation of the AC System. They system is illustrated in figure 2-17.

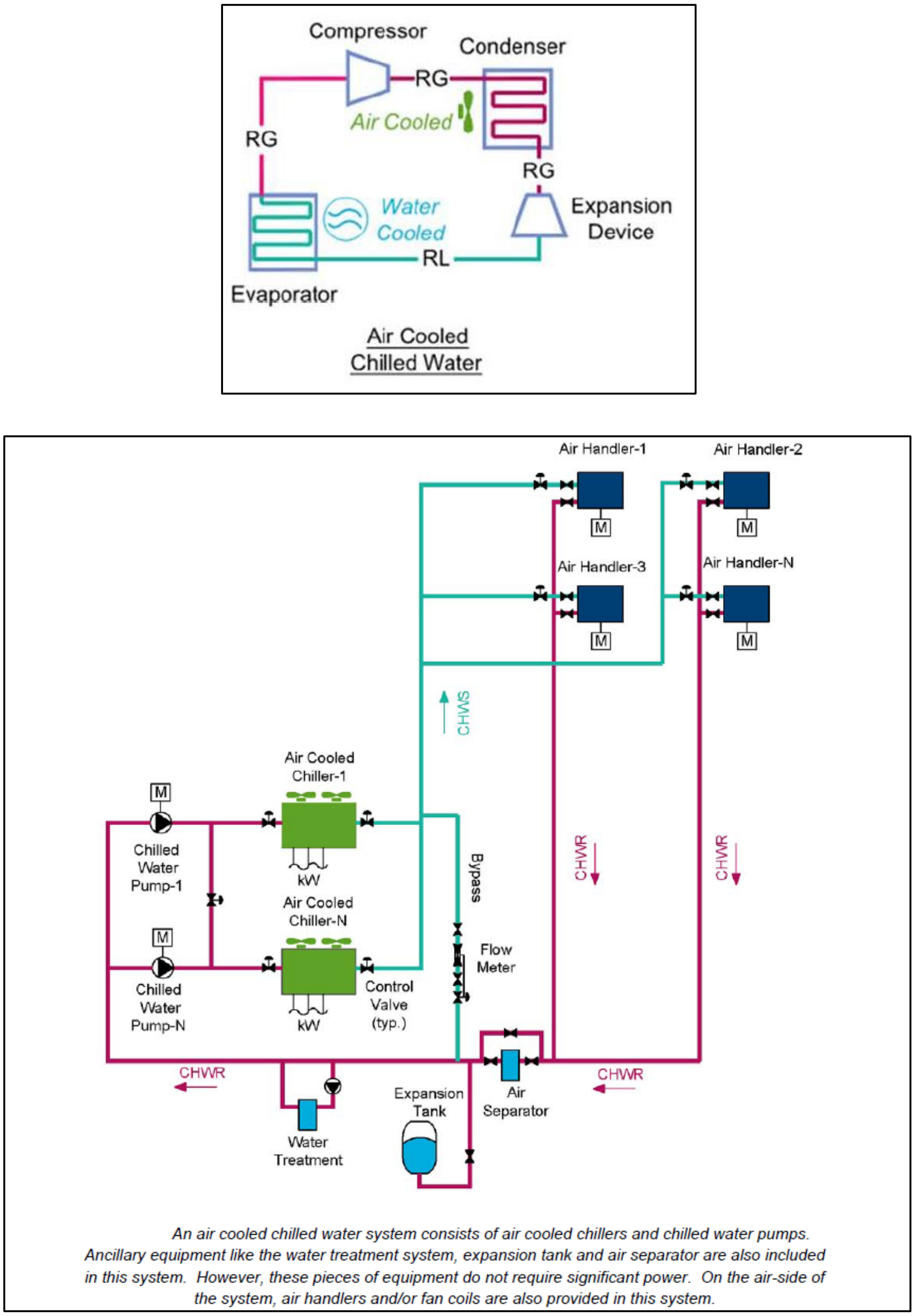


A split system typically consists of multiple indoor units and outdoor units. Refrigerant piping connects the indoor and outdoor units.

Figure 2-17: Split AC System Diagram (Engineering Pro Guides, 2019).

AIR COOLED CHILLED WATER AC SYSTEM

The system depends on air-cooled chillers, which utilize external air to deliver heat rejection for each refrigeration iteration cooling internal air through the operation of the AC System. (Engineering Pro Guides, 2019). They system is illustrated in figure 2-18.

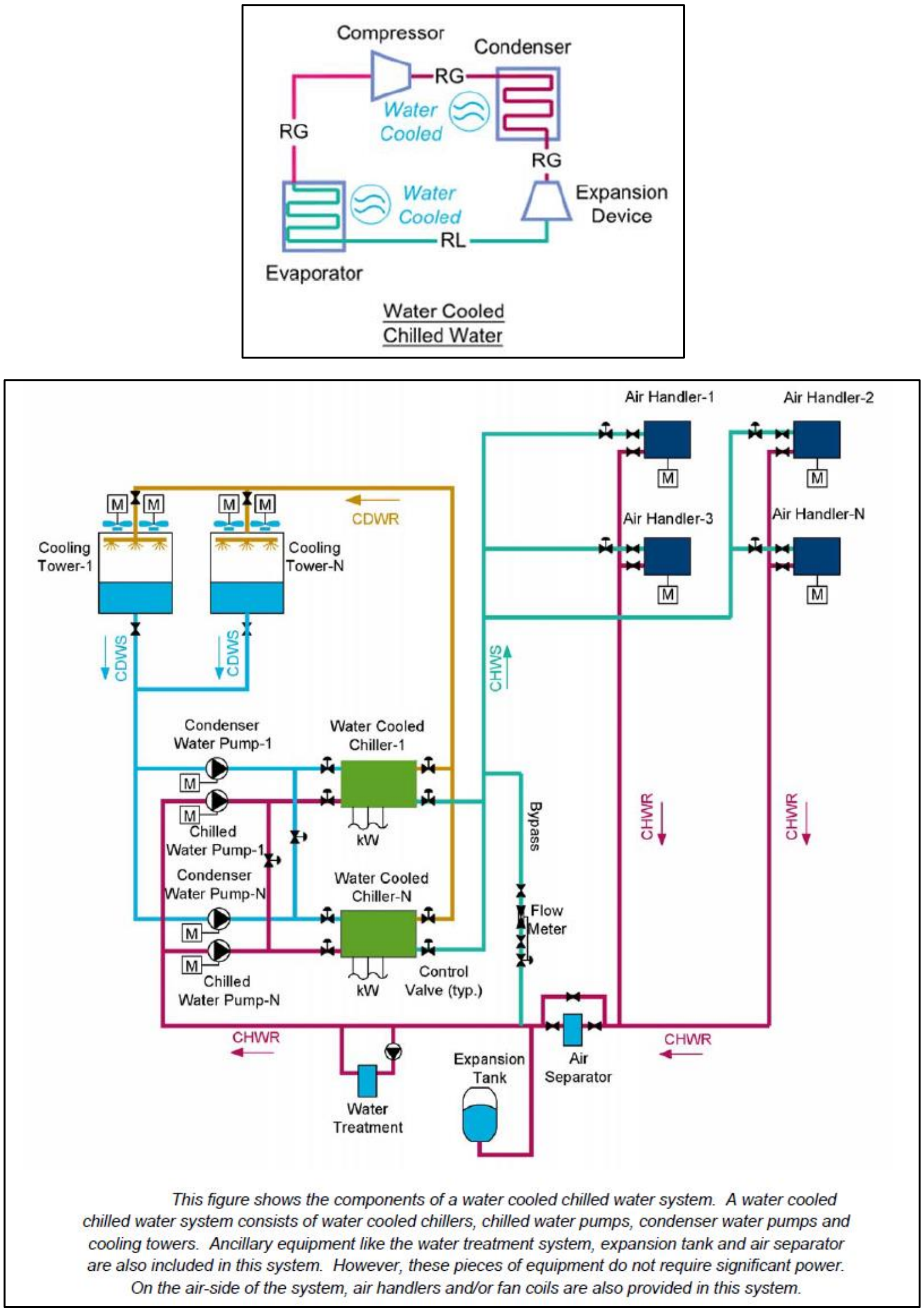


An air cooled chilled water system consists of air cooled chillers and chilled water pumps. Ancillary equipment like the water treatment system, expansion tank and air separator are also included in this system. However, these pieces of equipment do not require significant power. On the air-side of the system, air handlers and/or fan coils are also provided in this system.

Figure 2-18: Air Cooled Chilled Water AC System (Engineering Pro Guides, 2019).

WATER COOLED CHILLED WATER AC SYSTEM

The system depends on water-cooled chillers, which utilize condensed water from the condenser unit to produce heat rejection for each refrigeration iteration cooling internal air through the operation of the AC System. (Engineering Pro Guides, 2019). They system is illustrated in figure 2-19.



This figure shows the components of a water cooled chilled water system. A water cooled chilled water system consists of water cooled chillers, chilled water pumps, condenser water pumps and cooling towers. Ancillary equipment like the water treatment system, expansion tank and air separator are also included in this system. However, these pieces of equipment do not require significant power. On the air-side of the system, air handlers and/or fan coils are also provided in this system.

Figure 2-19: Water Cooled Chilled Water AC System (Engineering Pro Guides, 2019).

2.2.8.3 WATER HEATERS

The two types of most commonly used water heaters:

STORAGE WATER HEATERS

Storage Water Heaters, which is illustrated in figure 2-20, contain a vessel that keeps water warm and available to be used whenever required. When the hot tap is turned on, hot air is drained from the top of the storage tank, and cold water goes to the tank’s end to ensure that the storage tank is filled at all times.

Domestic heaters differ in size but typically have a size of 50 to 400 liters and use natural gas or electricity as their energy source. They are regarded as fairly inefficient because of continuous water heating, which leads to a loss of energy where no warm water is required (e.g., during the night) (Energy Saver, n.d.).

Recently, to reduce this inefficiency, solar energy has been considered an alternate solution. It harnesses the sun's energy in solar collectors that retain the warm water in the water heaters for storage.

Figure 2-20: Storage Water Heaters (Energy Saver, n.d.).

TANKLESS WATER HEATERS

Tankless water heaters, which is illustrated in figure 2-21, heats water instantly as it flows by the heater, and so this gives the infinite and constant heated flow of water. If there is a need for warm water in a building, cold water is transferred to a gas-powered burner gas or an electrical water heating unit that transfers heat to the water and provides 7-17 liters of water per minute (as compared to electrical ones' gas-fired forms give greater flow rates). On the other hand, gas heaters don't supply warm water for multiple purposes in a house, and so multiple tankless water heaters for various appliances have to be separately installed or attached simultaneously to solve this issue (Energy Saver, n.d.).

Households that consume up to 180 liters of warm water a day can conserve 20 to 30 percent of energy if they use tankless heaters rather than traditional water heaters for storage. However, 30-45 percent savings can be attained when they are fitted at every outlet of warm water. The initial investment of tankless water heaters is greater than traditional storage water heaters, but it balances the higher selling price because of its longer operational period and reduced maintenance and energy costs. Tank-less water heaters typically have a life span of twenty years or more, relative to a storage water heater's ten to fifteen years of life expectancy (Energy Saver, n.d.).

Figure 2-21: Tankless Water Heaters (Energy Saver, n.d.)

2.2.8.4 BUILDING WINDOWS

Windows consists of glass and frame which 10 to 30 percent of the window area is taken up by frames; thus, their design must be considered. The U-values of a window are 4-10 times greater, which makes it accountable for the majority of a building's heat losses (Forughian and Taheri Shahr Aiini). It will require the following two elements to provide more sustainable windows:

1. Selecting the right material for window frames, which can be wood or aluminum. The least preferred is aluminum due to its high heat transfer coefficient, than Wood. Wood is the recommended form because of its favorable insulation properties (Forughian and Taheri Shahr Aiini).

2. Energy-efficient glass:

   Using a low-emittance (Low-E) material for coating– translucent coating which enables to building heat reflection and inhibits the transfer of heat from the hot space (indoor) to the cooler spaces (outdoor), thus decreasing loss of heat via the windows and, so the need for heating. Moreover, the Low-E material coating lets energy from the sun flow into a building and,therefore, passively heat it (Forughian and Taheri Shahr Aiini).

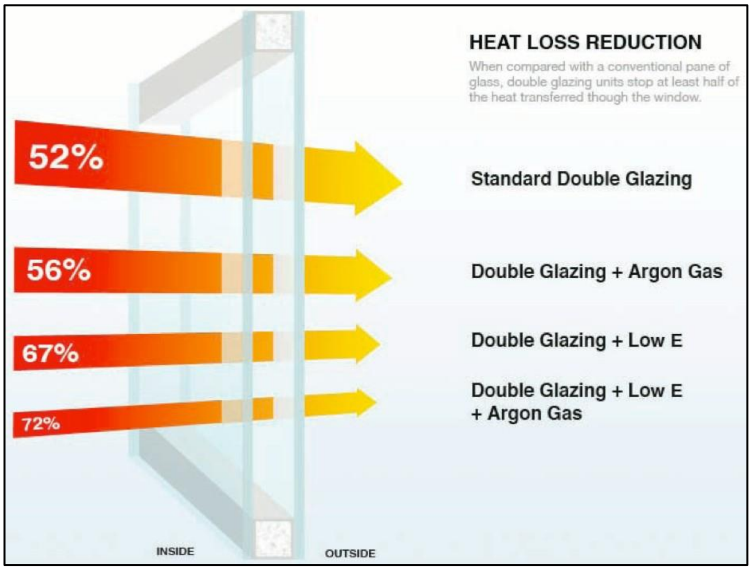


Figure 2-22: Glazing Benefits (Forughian and Taheri Shahr Aiini)

Glazing can have glass insulation and Low-E coatings. Argon or krypton are the gases used for insulation (Foroughian and Taheri Shahr Aiini). The kinds of glazing include single-glazed, which is least efficient, double-glazing, which is highly efficient. The performance of the window can be enhanced by noble gas (krypton/argon) insulation, triple-glazed, the very efficient but costly types of glazing (Foroughian and Taheri Shahr Aiini). The advantages of glazing are shown in Figure 2-22.

2.3 Sustainability of Building

2.3.1 Background on building Environmental Assessment Systems

There are Green building standards, rules, and regulations worldwide that serve as a reference for construction and architecture professionals. Setting standards like the International Organization for Standardization (ISO) and governmental or non-governmental organizations established rules and regulations which seek to fulfill specific goals focusing on sustainable building and construction and specific strategies for countries (ElFiky 2011).

Building Environmental Assessment Systems are tools to determine the environmental effects of buildings. It encompasses the common environmental factors of buildings like energy, water, materials, and waste, along with the evaluation of problems such as lighting, quality of indoor air, ventilation. These approaches for constructing environmental evaluation have been underway since the early 1990s. Most green building rating systems provide a wide-ranging variety of building styles and states; for example, various designs cover buildings of retail, industrial, and residential (Lee 2013). In addition, evaluation of these buildings can vary from new construction, shell, and core to current building situation. Building Research Establishment Assessment System (BREEAM) was a pioneer rating system. The rating system was developed by the British Research Establishment (BRE) with the aim of analyzing, assessing, and certifying sustainable standards of buildings. (Lee 2013).

Initially, the purpose of BREEAM was based on new construction phase buildings but was then expanded to cover the entire life cycle of a building. Also, the BREEAM approach has formed other rating systems like LEED, ESTIDAMA Pearl Rating System (PRS), CASBEE, etc. An increase in the total of green building rating systems was because of the speedily growing effect of buildings on the environment and its resources; thus, the performance of the building had to be evaluated to determine and grant buildings depending on their sustainability level. The following are the requirements that many green assessment systems need, which are water, materials, energy, indoor air quality, and sites. (Lee 2013).

Reference to studies conducted by R. S. Hastings and M.Wall, environmental assessment systems for buildings, products, and processes vary from a single dimension to a multi-aspect assessment (Hastings et al., 2012). The authors have identified three key methods for building's sustainability assessment:

1. Cumulative energy demand systems (CED): to measure the consumption of energy.

2. Life cycle analysis systems (LCA): It just takes into account the factors related to the environment.

3. Total quality assessment systems (TQA): also defined as the LEED and BREEAM sustainability rating systems. It calculates the ecological, economic, and Social elements; it is also.

CED and LCA use the quantitative measurement approach, while TQA may use both qualitative and quantitative methods of evaluation (Hastings et al., 2012). Worldwide, there has been much research in both developing and developed countries in the area of green building. (Hastings et al. 2012) propose that shared interest and focus exists across most of the green building rating systems analyzed by assigning importance to two key features, which are process (method for procedure implementation), and outcome (method for procedure assessment) (Hastings et al. 2012).

There are more than 40 (TQA) generally referred to as green building rating systems; like ESTIDAMA Pearl rating system in Abu Dhabi UAE, CASBEE in Japan, LEED in the United States, BREEAM in the United Kingdom, and Tarsheed rating System and Green Pyramid rating system (GPRS) in Egypt (Hastings et al. 2012).

Table 2-1: Summary of Green Rating System Embraced from (U.S. Green Building Council), (BREEAM), (green building council Australia), (Green Building Initiative), (DGNB – German Sustainable Building Council), (Building & Construction Authority Singapore), (HKGBC).

Rating Systems	**LEED**	**BREEAM**	**GREEN STAR**	**GREEN GLOBES**	**DGNB**	**BCA GREEN MARK**	**GBI**	**BEAM PLUS**	**TARSHEED**	**Green Pyramid**
Organization	*USGBC*	*UK BRE*	*GBCA*	*ECD*	*DGNB*	*BCA*	*PAM and ACEM*	*HKGBC*	*EGBC*	*EGBC*
Origin	*USA*	*UK*	*Australia*	*Canada*	*Germany*	*Singapore*	*Malaysia*	*Hong Kong*	*Egypt*	*Egypt*
Year	*2000*	*1990*	*2003*	*2000*	*2007*	*2005*	*2009*	*2010*	*2012*	*2009*
Application	*World Wide*	*World Wide*	*World Wide*	*World Wide*	*World Wide*	*Singapore & South Asia*	*Malaysia & South Asia*	*Hong Kong & China*	*Egypt*	*Egypt*
LOGO	U.S. GREEN BUILDING COUNCIL LEED USGBC	BREEAM	greenstar	GREEN GLOBES	DGNB	BCA GREEN MARK	green building index	HKGBC BEAM Plus 綠建環評	EGYPT GREEN BUILDING COUNCIL TARSHEED EGGBC	GREEN BUILDING COUNCIL EGYPT
Certification Levels	*Basic 40 - 49*	*Unclassified < 30%*	*Minimum Practice = 1 Star*	*1 Green Globe*	*Bronze=> 35%*	*Certified => 50%*	*Certified => 50%*	*Bronze => 40%*	*Bronze => 40%*	*GPRS Certified => 40%*
	Silver: 50 - 59	*Pass => 30%*	*Average Practice = 2 Star*	*2 Green Globe*	*Silver=> 50%*	*Gold => 75%*	*Silver => 66%*	*Silver => 55%*	*Silver => 50%*	*Silver Pyramid => 50%*
	Gold: 60-79	*Good=> 45%*	*Good Practice = 3 Star*	*3 Green Globe*	*Gold=> 65%*	*Gold plus => 85%*	*Gold => 76%*	*Gold => 65%*	*Gold => 60%*	*Golden Pyramid => 60%*
	Platinium: > 80	*Very Good => 55%*	*Best Practice = 4 Star*	*4 Green Globe*	*Platinium => 80%*	*Platinium => 90%*	*Platinium => 86%*	*Platinium => 75%*	*Platinium => 70%*	*Green Pyramid => 80%*
		Excellent => 70%	*Australian Excellence = 5 star*	*5 Green Globe*						
		Outstanding => 85%	*World Leadership = 6 Star*							

2.4 HIGH-RISE BUILDINGS CASE STUDIES

2.4.1 THE EMPIRE STATE BUILDING

The Empire State Building was constructed in 1930, and the grand opening was in 1931. The Empire state building is the world's tallest free-standing structure from 1931 to 1967, which was considered to be the tallest skyscraper for over 40 years (ESB, 2020). The Empire state building is a mixed-use building with 102 stories with a roof height of 380m and a total height of 443.2m, including the antenna. It is ranked the seventh tallest building in New York City and the sixth tallest skyscraper in the United States (ESB, 2020). It is also ranked as the 45th tallest building in the entire world. The building consists of 6,500 Windows, 73 Elevators, and a total floor space of 241,000 Square Meters or 2,768,591 sq ft.

The building structure is a steel structure, and the main material used for its construction was steel, while other materials such as granite, limestone, and brick were used for the exterior phases. (ESB, 2020). The mortar and concrete that was used in the Empire state building used blast furnace slag, giving mortar and low concrete permeability, decrease cement usage to 40% increasing sustainability, higher compressive strength by 19 %, and 25 % increase in tensile strength leading to a higher, therefore more sustainability (ESB, 2020).

High-rise buildings consume 80% of the city's total energy consumption of New York's City and the Empire State Building is considered one the highest energy consumption and CO_2 producer in New York City. The Empire State building is a 79-year-old building which had an 11 million dollars annual electricity utility bill with a yearly consumption of 9.5 megawatts equal to the consumption of electricity of 40,000 single-family houses, and a 25,000 Metric tons of CO_2 emission per year, making the Empire state building the highest energy consumption and CO_2 producer in New York City (ESB, 2020).

In 2008, Sustainable Empire state building Retrofit was taken by New York City and several organizations like Jones Lang LaSalle (JLL), Clinton Foundation, Clinton Climate Initiative, Johnson Controls, and Rocky Mountain Institute, costing about 550 million dollars. The objective of the Retrofit is to decrease annual energy consumption by 38.4%, which is equal to 4.4 million dollars, and lower the CO_2 emissions in 15 years by 105,000 Metric tons as if taking 20,000 cars off the road. Such Retrofit Project could pay back its cost in only three years (ESB, 2020).

Moreover, the Retrofit has two influential drives, which are Converging Forces and Business opportunities. The Converging forces include the need to develop more sustainably efficient business practices, Corporate trend towards GRI reporting and reduction of GHG emissions, and pressures from Customers, Employees, and shareholders (ESB, 2020).

Business opportunities include a reduction in operating costs due to efficiency, an increase of competitiveness and marketing capabilities using sustainability, improving the work environment and productivity for employees, cashflow improvement due to energy saving, and increase return of investment and net present value (ESB, 2020).

According to (ESB, ND), The Retrofit is capable of causing an energy reduction of 38% and reduction of CO_2 Emissions by 38%, equal to 105,000 metric tons and a return on investment of 22 million over 15 years as seen on the figure 2-23 below. Figure 2-26 explains annual Energy Savings based on sustainable measures taken.

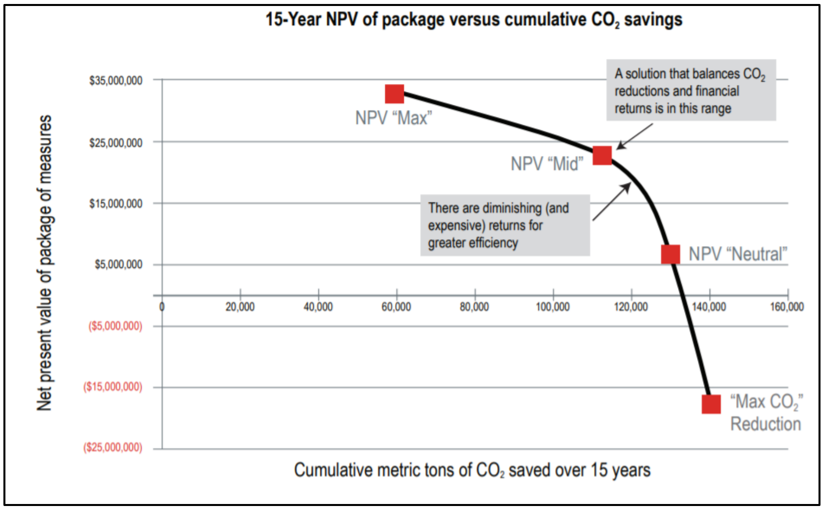


Figure 2-23: 15 Year NPV VS CO_2 SAVING Embraced from (ESB, ND)

In addition to that, the Empire State Building Retrofit using LEED Guidelines provided sustainable tenant design guidelines improving tenant indoor environment quality and improving thermal comfort by using better double-glazed windows, radiation barriers, AHU alterations, Improved space lighting providing more sustainable lighting and power supply leading to lower energy consumption, energy-saving, lower CO_2 consumption and return in investment. Below, the figures explain how adding tenant spaces to the retrofit decreases annual energy consumption and using sustainable methods in tenant spaces to the project affects the decrease of the annual energy savings (ESB, 2020). Figure 2-24 and Figure 2-25 explains the difference of energy saving base building and within Tenant Spaces.

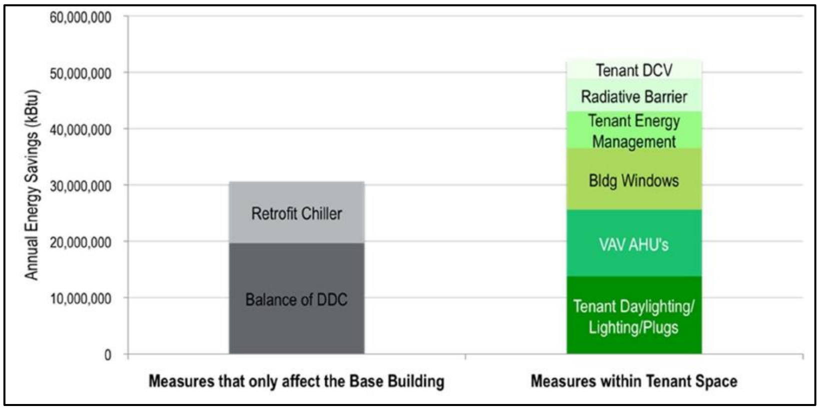
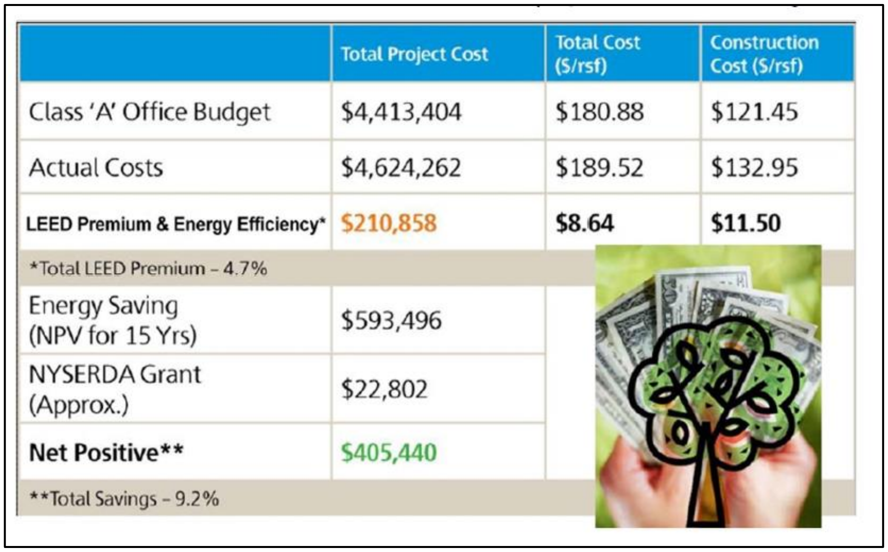


Figure 2-24: Energy Saving Base building vs. within Tenant Spaces Embraced from: (ESB, ND)



	Total Project Cost	Total Cost ($/rsf)	Construction Cost ($/rsf)
Class 'A' Office Budget	$4,413,404	$180.88	$121.45
Actual Costs	$4,624,262	$189.52	$132.95
LEED Premium & Energy Efficiency*	$210,858	**$8.64**	**$11.50**
*Total LEED Premium – 4.7%			
Energy Saving (NPV for 15 Yrs)	$593,496		
NYSERDA Grant (Approx.)	$22,802		
Net Positive**	$405,440		
**Total Savings – 9.2%			

Figure 2-25: Tenant (Skanska) studies on their own Costs and Savings Embraced from: (ESB, N.D)

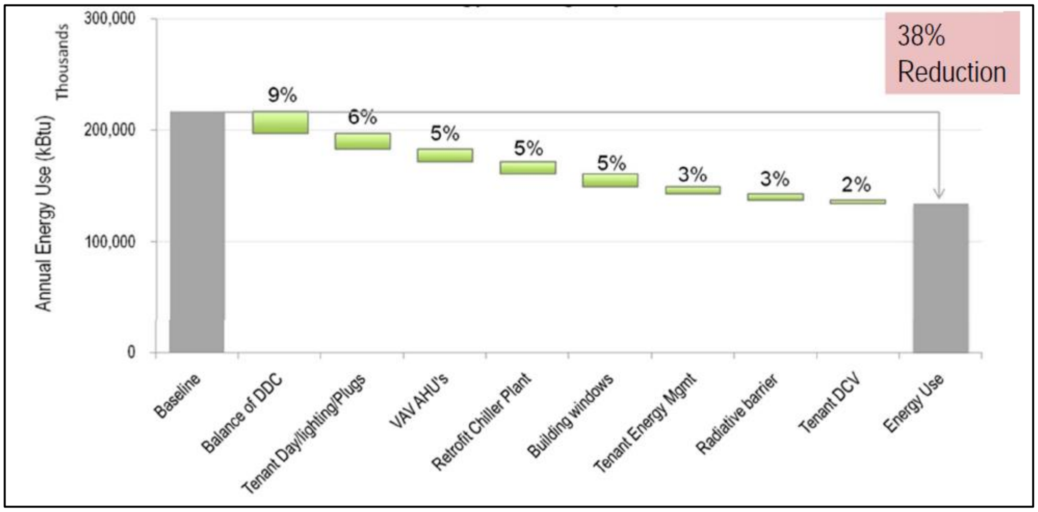


Figure 2-26: Annual Energy Savings based on eight measures taken. Embraced from (ESB, N.d)

2.4.1.1 THE EMPIRE STATE BUILDING SUSTAINABLE RENOVATION PROJECT.

The sustainable renovation Project consists of three phases which include:

EMPIRE STATE BUILDING RETROFIT PHASE 1

The empire state building Retrofit Phase 1 will provide 7.9% energy saving, a decrease of CO_2 consumption by 22,000 metric tons over 15 years which like removing 4,000 cars out of the streets and return of investment would be 1 million dollars per year. The Phase 1 renovation will include:

1. Window Refurbishment and Reusing Materials:

The window Refurbishment consists of 6514 duo-pane windows on a facility on site. The refurbishment increases the insulation from Grade-R 2 to Grade-R8, which has higher insulation of heat transfer as the higher the R-value, the less heat transfer. Moreover, Krypton/argon gas is filled (ESB, 2020). Illustrated in figure 2-27.

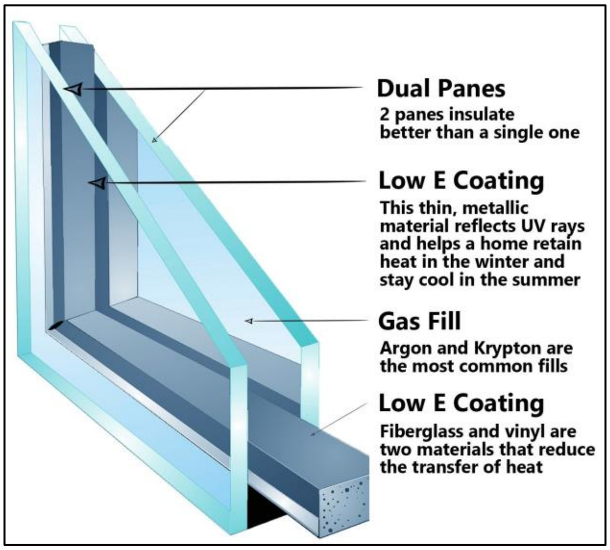


Figure 2-27: Double Glazed windows; Embraced from (ESB, N.d)

2. Radiative Barrier:

A radiative barrier is a building material that is used for slowing down heat transfer and reflection of thermal radiation. Renovations consist of installing more than 6000 radiant barriers behind each radiator unit through the building premises, illustrated in figure 2-28 (ESB, 2020).

Figure 2-28: Empire state building windows; Embraced from (ESB, 2020)

EMPIRE STATE BUILDING RETROFIT PHASE TWO

The empire state building Retrofit phase two will provide 19.1% energy saving, a decrease of CO_2 consumption by 50,000 metric tons over 15 years which like not burning 199,000 barrels of crude oil, and return of investment would be 2.2 million dollars per year. The Phase two renovation will include:

1. Renovation of Chiller plant: four electric chillers were renovated to provide a more efficient chiller plant (ESB, 2020).

2. New Air Handling Unit (AHU) and Smart wireless control network: A more advanced system is implemented to monitor wirelessly and ensure smart and efficient air quality. The works renovation of VAV air handling units, DDC controls, Demand Control Ventilation (ESB, 2020).

EMPIRE STATE BUILDING RETROFIT PHASE THREE

The empire state building Retrofit phase two will provide 11.4% energy saving, a decrease of CO_2 consumption by 31,000 metric tons over 15 years which is more CO_2 than 1,340,000 trees cleanse or remove in one year and return of investment would be 1.3 million dollars per year. The Phase three renovation will include:

1. Energy Efficient Lighting and Plugs: Energy Efficient CFL and LED bulbs and smart plugs with motion and thermal sensors to sense the presence of a person in the room and, based on that, to turn the lights on or not (ESB, 2020).
2. Daylighting: The daylighting concept is providing measures to use daylight in areas where has sufficient daylight and turn off the lights in these periods to improve energy saving (ESB, 2020).
3. Tenant Energy Management: an energy management system and a dashboard that provide live time estimates to the tenant for energy consumption and where energy is lost to ensure the reduction of power consumption and increase energy saving (ESB, 2020).

OVERVIEW ON EMPIRE STATE BUILDING USAGE OF MATERIALS

The building was originally constructed using stonework, and steel beams were prepared on an offsite location to ensure the CO_2 emissions were contained (Grabianowski, 2020). It also ensured that the workers were not negatively affected by materials used, which is perceived as key in Green concrete ratings (Liew, Sojobi, & Zhang, 2017). The building was constructed with about 57,000 steel columns and 62,000 cubic yards of concrete (ESB, 2020). It is also reinforced by the use of limestone, granite, and aluminum materials. The usage of the materials for recycling and optimization to environmental and social benefits impacts the certification credit. The steel used led to the slap depth allowing the building to resist tension and improve its life cycle by about 20-30% percent. Besides that, the building retrofit engages in sustainability according to LEED through the recycling of tenant waste and construction debris (Bloomfield & LaSalle, 2011). The building is sustainable as it engages in the recycling of all possible products in the building, and through the tenant energy management system, it continues to engage in the attainment of mandatory green requirements. The requirements increase its sustainability of the high-rise building in the environment. Rainwater is captured and recycled throughout the building for cleaning and other service activities. Also, the waste material experiences a 90% target of recycling through waste management and waste education to its tenants and the implementation of a system for the whole building waste recycling process (ES, n.d.).

OVERVIEW ON EMPIRE STATE BUILDING USAGE OF ENERGY AND RESOURCES SAVING

The empire state building is considered the largest purchaser of renewable energy, anticipated to total about $55 million in cost savings related to the alternative of electricity consumption (ESB, 2020). Thus, the use of energy for the building does not harm the environment in any way. The building retrofit programs are focused on ensuring that sustainable sites are attained. This has reduced energy consumption by about 38%, making millions of energy costs on energy consumption (ES, n.d.). The energy programs reduce energy consumption costs by about $7.5M in the last three years (ESB, 2020). The savings are efficiently leading to a guarantee of 15.9% reduced costs of energy totaling about $2.8M (C40 cities, 2014). This is attained through the improvement of green materials and resources in the building to provide lessons on the sustainability of such buildings. Innovation and Design in the building are perceived as the operations in the building.

The innovative changes that the building has experienced over time, perceived as green retrofitting, have improved energy and environmental performance upgrades (ESB, 2020). The retrofits perceived usage of energy fixtures that conserve energy by photo-sensor dimmers to ensure any natural light is used to reduce unnecessary electrical lighting (Begec & Hamidabad, 2012). The heating and air conditioning processes and systems have been improved to impact the negative environmental impacts on the building, the environment, and the occupants. Water efficiency is achieved through the conservation of water, retention and capturing of rainwater, and re-use of the water, among other ways (Al-kodmany, 2018). Such retrofit made the empire state building a green building and earning the gold LEED certification. *Moreover*, The Gold certification is a representation that the building during its retrofit project used recyclable materials and energy-efficient/ saving methods. The building presents that by 2050 it will have a 75% reduction of CO_2 emissions to benefit the atmosphere and avoid climate changes (Bloomfield & LaSalle, 2011). Smart and efficient technology will constantly be used also for water and energy efficiency. The LEED certification for sustainability was also awarded based on other activities such as the installation of ultra-low fixtures in the restrooms of the buildings, the availability of green cleaning supplies, and pest control products (Zhou & Wong, 2015). The factors present that the life cycle cost of the building will improve constantly based on the developments expected, and the saving attained. The rating is based on the fact the building has high levels of insulation based on the glass and aluminum used that reduces the consumption of energy (Zhou and Wong, 2015). Resources savings are conducted through the fixtures that improve the sustainability of the building. That is, the building uses a real-time energy management system to monitor how the tenants used energy-based on software programs that can monitor each tenant individually. The building also has ultra-low fixtures that improve the water-saving processes. Utility water usage undergoes audits to ensure the efficiency of water usage. That is, it ensures that the water used for heating and cooling activities is the appropriate size (ES, n.d.). This is attained in relation to sub-metering and monitoring the usage of the water. Hence efficiency in water-saving is attained. Waste management also ensures resource-saving where waste diversion processes have been developed to meet the NYC legislation requirements (ES, n.d.). It is also perceived on tenant education and recycling. The building also undergoes inspections on IEQ testing, which ensures that the building has no volatile organic compound materials. It also ensures the air purification is efficient and reduction of the CO_2 (ES, n.d.).

CONCLUSION

Therefore, the building CO_2 emissions are reduced, and it serves a lot of people for productivity with low costs related to the energy and resource efficiency that is improved with retrofits. The anticipated CO_2 emissions account for 105,000 tons reductions in the next 15 years (LaSalle, 2010).

Thus, the life cycle fee of the construction is decreasing with energy and resource efficiencies. The CO_2 of the building has been reduced through the greenhouse gas inventory equipment that ensures that the operations of the building do not affect the global warming proliferation. The energy, water, and environment management systems ensure that the building is sustainable.

2.4.2 THE BURJ KHALIFA

The Burj Khalifa lies in the downtown of Dubai, United Arab Emirates, a mixed-use tower that consists of a 160 storied tower with 2957 underground parking spaces, adjacent podium, three-story pool annex, and connected six-story office annex.

The building consists of Hotels, Residential, Mechanical, Sky lobbies, Observatories, Offices, Restaurants, Broadcasting, and spire. The Burj Khalifa has three entrances for Hotel Residence, Tower Residence, and offices. The building construction started in 2004 and ended five years later in 2009 with a cost of 1.5 billion dollars and a height of 828m. The Burj Khalifa total area is 465,000 m2 divided into 280,000 m2 tower with a total podium area of 186,000 m2. In addition to that, the concrete used is 330,000 m3, Steel rebars of 39,000 metric tons, and Curtain walls: 83,600 m2 of glass and 27,900 m2 of metal.

Moreover, the Burj Khalifa consists of 57 elevators and eight escalators. The building aims to improve sustainability by increasing the functionality of the building (Julien, 2018). Burj Khalifa is considered to be twice higher than the Empire State Building. The Burj Khalifa is still not LEED Certified, however by the sustainable practices that have been implemented in the building throughout the years, it may be considered to be LEED Certified. (Fact Sheet, 2016).

2.4.2.1 CONSTRUCTION AND MATERIALS OVERVIEW

The building ensures the environmental impacts are positive based on the resources and materials used throughout the building. The procurement of the construction materials followed the necessary processes to guarantee the quality of concrete used, among other supplies. That is, the building has the capacity of withstanding pressure and utilizing the heat in Dubai for its operations effectively. The building construction materials, green concrete, and energy-efficient processes ensure that the life cycle cost of the building is low. Thus, the building remains beneficial to its occupants and the environment. The building used construction materials that increase its durability and strength, which is key to ensuring the safety of the building occupants and the external environment (Burj Khalifa, 2020). In addition to that, the building has a complex waste management process that collects, disposes of solid wastes, and recycles materials collected from the entire building. It monitors the systems used for recycling to ensure sustainability compliances are achieved. The waste management process is efficient since it improves the costs of disposal, improving the building efficiency and performance. (Fact Sheet, 2016)

During the construction, the engineers engaged in a wind tunnel testing process to ensure that the effects of the wind on the structure and occupants were safe. Testing involved the stack effect phenomenon to ensure the structure could withstand pressure and temperature changes. The floor plans also present that the needs of the occupants were met for functionality and comfort. The core walls are also reinforced with concrete from the ground level. This is because the materials used to improve the life cycle of the structure by more than 30% percent, which is the expected rate of materials impact on the life cycle of structures. This is a process that ensures the stability of the structure, where the efficiency of the materials is also perceived with the expected impacts on the environment. The main construction material is steel; the building is then reinforced with concrete everywhere, showing the architectural design that makes the structure sustainable (Fact Sheet, 2016). The concrete material used for the structure is sturdy and tough, which decreases life cycle expenses.

The building used about 330,000 cubic meters of concrete, and the foundation used about 45,000 of the total cubic (Burj Khalifa, 2020). The foundation of the building consumed about 58,900 cubic yards of concrete that weighed more than 110,00 tons (Sloan, 2016).

The concrete was reinforced with steel rebar, among other recyclable and renewable materials such as aluminum, glass, and silicone. The concrete used is high-performance concrete given that it can withstand tons that attempt to bear it down with the increased compressive strength. The construction consumed 431,600 cubic yards of concrete and yards of rebar laid (Sloan, 2016). The lifecycle of the materials affects the sustainability of the building; thus, the steel and aluminum advance the life cycle of the structure (Emirates 24/7, 2010). The Burj Khalifa superstructure is structured on a large reinforced concrete raft, which is supported with bored reinforced concrete piles, as seen in the figure 2-29 below. The raft foundation design was established on a comprehensive study of geotechnical and seismic load studies. In addition to that, the raft foundation is a 3.7m thick raft that was constructed and poured in phases. The raft foundations consist of 12500 m3 of C50 grade self-consolidating concrete (SCC). In addition to that, the raft is supported by 194 bored cast-in-place piles with a weight of 3000 metric tons each: 1.5 m diameter and 43m length. The piles use C60 grade SCC concrete providing high density and low permeability.

Moreover, Burj Khalifa Raft is protected from corrosive materials available in local groundwater by a complex cathodic protection system. The benefits of using SCC is that it provides high strength and durability, which leads to a longer life cycle and higher sustainability, faster and easier pumping, swift placement without vibration or mechanical consolidation, which may provide minor cracks within the structure, lower noise levels, stronger bond to reinforced steel, and increased structural integrity (Emirates 24/7, 2010). Besides that, the use of cathodic protection provides higher durability and a longer life cycle minimizing repair and renovation and providing higher sustainability of the building. Moreover, the challenge that was faced in the mix design for the structural foundations and core of the Burj Khalifa tower is to make sure that 170,000m3 of concrete with 80N/mm2 compressive strength withstand being pumped without any interruption from large heights over 600m and extreme climate and humidity of the UAE. The challenge was solved by using an admixture to reduce the water/cement ratio by using BASF'S MasterGlenium high range water reducing admixture (Emirates 24/7, 2010).

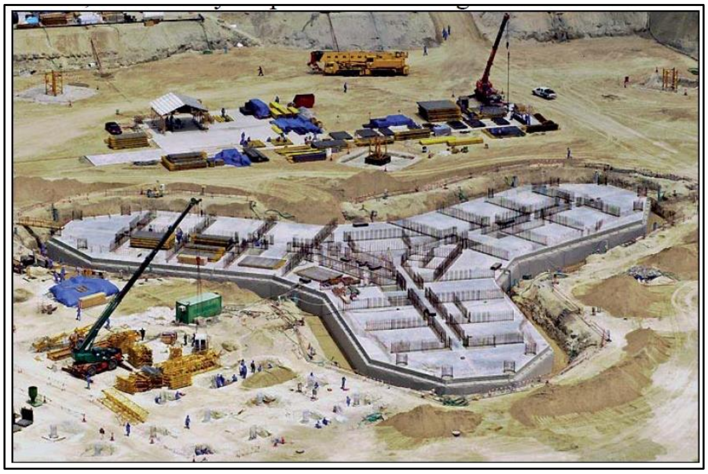


Figure 2-29: Burj Khalifa Foundations (Emirates 24/7, 2010).

Likewise, the walls and columns use High-performance self-consolidating concrete (SCC) concrete of C80 and C60 mix designs consist of Portland cement, 13–20% fly ash with silica fumes of 5–10%., local aggregates approximately 50%, and Basf superplasticizer providing low permeability, high workability, and high durability. The C80 concrete Youngs modulus of 43,800 N/mm2 at 90 days (Emirates 24/7, 2010).

2.4.2.2 ENERGY SAVING METHODS OVERVIEW

Burj Khalifa has led to the highest savings based on the atmosphere provided throughout the building. The building has silicone, aluminum glass frameworks in the windows to allow natural light that ensures a resource-saving method. The processes reduce the need for source consumption of energy during the day when the light is shining bright. Energy efficiency is attained at the building through silicon, glass, and aluminum, which ensures that energy is retained and saved. It also has a glazing that reduces the transmission of heat, which saves energy as well (Burj Khalifa, 2020).

Solar panels are used to heat the water while leveraging the power for all electricity requirements. Solar panels increase efficiency as they meet the demand of heating all the water for the residents. Also, the solar panels in the building and cooling systems for recycling energy ensure the source energy consumption is reduced. The solar energy attained can be used to heat about 140,000 liters of water used for the building operations, which saves millions through energy conservation (Emirates 24/7, 2010).

The water heated with solar energy leads to savings of 3,200 kilowatts of energy each day, which total to 690MWh energy every year. Solar energy is collected through panels on the roof and sides of the buildings that collect natural energy (Emirates 24/7, 2010). The building has 378 panels of solar energy that capture, conserve and reuse the energy for operations in the building (Emirates 24/7, 2010).

Other energy resources saving methods perceived in the building include the thermal wheels, speed drives fixed on air coolers, solar shading, and water circulating equipment that increase energy efficiency (Emirates 24/7, 2010). Overall, the energy consumption throughout the building is reduced.

2.4.2.3 WATER-SAVING METHODS OVERVIEW

The process ensures that the building increases water efficiency and water-saving costs as the building captures water through condensation and reuses the water for activities and operations in the building. Thermal wheels in the building ensure that the air is fresh, among others.

The building resources use high leading to numerous economic modes, energy saving costs, and reduced pollution benefitting the environment (Emirates 24/7, 2010). The building also has water-saving methods where water condensed in the building is captured, stored, and reused. An on-site irrigation tank was used for storing the water from condensation, which is about 15 million gallons. The on-site irrigation tank is also high on water conservation and saving, as the water is used for the landscaping (Emirates 24/7, 2010).

2.4.3 CONCLUSION

Thus, The Burj Khalifa ensures low Carbon emissions and energy consumption which has a huge impact on the environment. Such sustainability is achieved by the usage of sustainable resources and materials throughout the building. As, the construction materials followed the necessary processes to guarantee the quality of concrete used, among other supplies. The building has the capacity of withstanding pressure and utilizing the heat in Dubai for its operations effectively. The building construction materials, green concrete, and energy-efficient processes ensure that the life cycle cost of the building is low. Thus, the building remains beneficial to its occupants and the environment throughout its lifespan.

2.5 SUSTAINABILITY CHALLENGES

To date, the inability to fully apply construction ways that are sustainable on a huge level is obvious worldwide, and mainly in developing nations. It can be due to many challenges (United Nations, 2018):

- Severe fragmentation as any single development's emission reduction potential is negligible, and reductions can be noticed only at the aggregate level.
- Lack of ownership as various stakeholders involved in decision-making at different stages of the lifecycle of a project comprising contractors, and developers
- Great expense of applying construction methods that are sustainable and very weak economic opportunities to encourage owners and/or occupants for energy savings.
- Absence of knowledge of the significance and future effect of sustainable development.
- Absence of metrics for calculating energy efficiency in buildings.

2.6 LIFE CYCLE ANALYSIS LCA SOFTWARE’S

A software system created in Germany and named GaBi has drawn interest from experts for its analysis of product life cycle waste emissions. GaBi-supported procedures comply with the SETAC Global Guidance Principles for Life Cycle Assessment Databases (SPHERA, 2018). It model’s each aspect of the production of a product from the perspective of a life cycle, enabling businesses to make intelligent choices about their product design and manufacturing in a sustainable way. It is an efficient and scalable tool that assesses emissions from the production of any product varying from a toothpick to a huge building.

Moreover, GaBi has a readily available content database outlining the energy and environmental effects of each raw or refined element of a manufactured item being purchased and refined. Moreover, it examines the environmental effects and offers alternate production, distribution, recyclability, emissions, and sustainability solutions (SPHERA, 2018).

2.7 HYPOTHESES

This Study literature review has proposed a variety of hypotheses that provide the basis for the new system design:

1. The world is changing gradually and irreversibly by a number of megatrends.
2. Rising urbanization would result in greater stress on the environment.
3. Tackling global warming should be a primary concern in preventing potential disasters.
4. Changing the building structures could significantly reduce global warming.
5. Building structures have a lot greater effect on the environment during the use phase.
6. A number of barriers threaten the implementation of construction practices that are sustainable.
7. There are many ways to reduce the carbon lifecycle emissions of buildings.
8. A principal component of Egypt's GHG reduction is to build sustainably.
9. The cement production process is a major factor in carbon dioxide emissions associated with construction materials.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Through this study, a model will be developed for Egyptian high-rise Mixed-use buildings for the evaluation and analysis of Carbon footprints. The model embraces a top-down approach which is influenced by the sustainable methods mentioned in the literature review in Chapter 2. The model evaluates energy and carbon footprints according to the construction phase and operation phase of a high-rise building. The model methodology's initial aim is on high-rise mixed-use buildings in Egypt; however, it can be implemented into various construction divisions in different regions with similar geographic and climate conditions. Such duplication in other regions can be reached by minor adjustments in the primary quantitative assumptions for high-rise building construction, geographic location, and climate.

3.2 MODEL DESIGN

The model design was based on a top-down method and developed by findings of the literature review in Chapter 2. The model design is divided into two divisions: Construction Carbon emissions savings and Operational Carbon emissions savings. As the structure of the model had been theorized, the additional development needed is for the enhancement of the numerical factors related to each category that influence CO_2 Emissions and energy consumption. Such Further development was difficult to inherent in this model due to the absence and scarcity of High-rise building construction research in Egypt. Therefore, through this investigation, alternative approaches have been examined to be able to develop the model by relying on data from the United States, which had many pieces of research and sources related to High-rise buildings, CO_2 emissions factor, and energy consumption factors. However, the study will focus mainly on southern US states, which have similar climate and geographical locations to Egypt. The figure 3-1 illustrates the model flow chart.

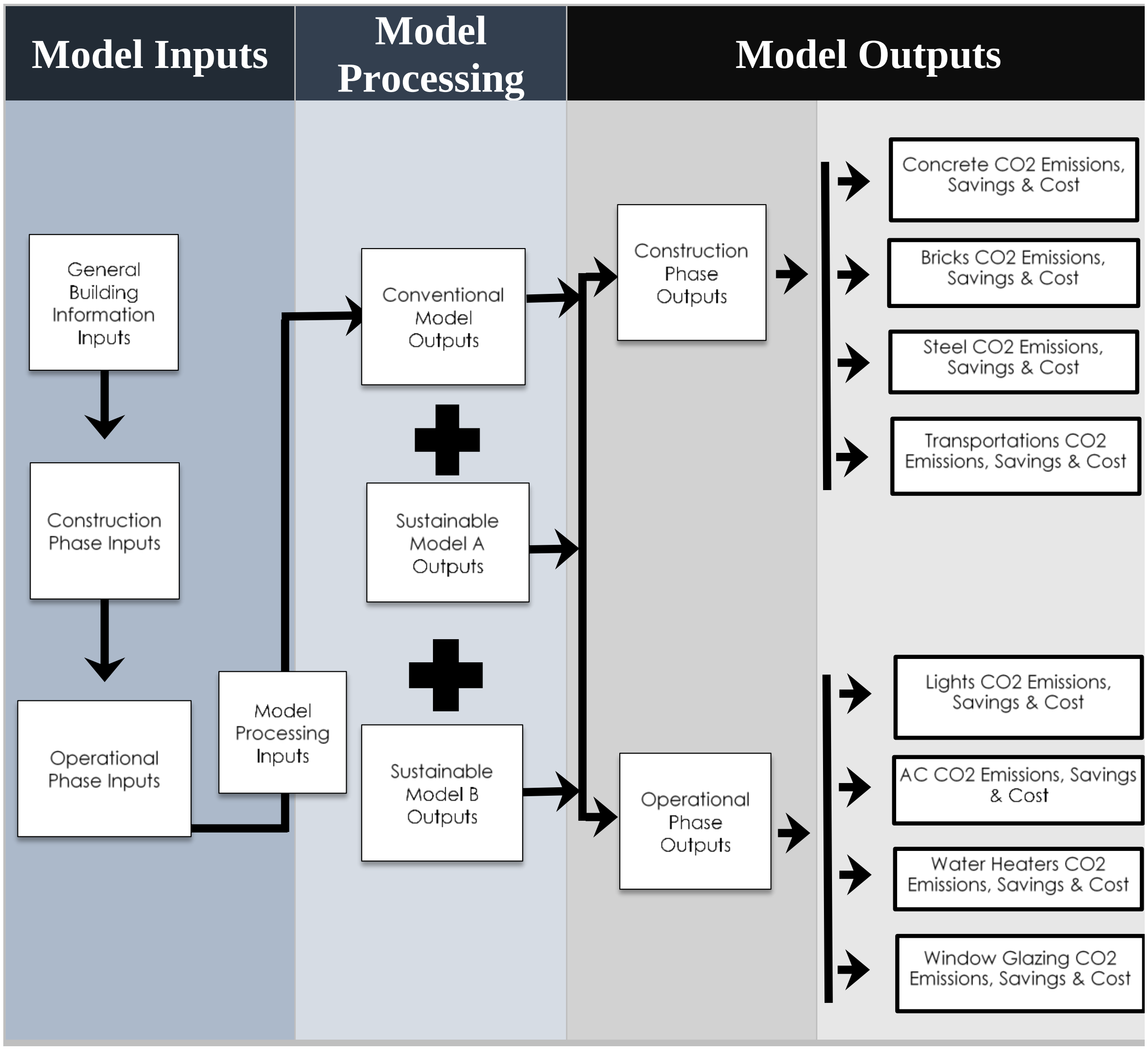


Figure 3-1: Model Flow Chart

3.2.1 MODEL CONSTRUCTION PHASE DESIGN

The Model Construction Phase design focus on the central source of Carbon emissions which are building materials; hence, the model design is based on the selection, management, measurement, and analysis of materials that are more sustainable, providing fewer carbon emissions, in comparison to traditional construction materials that provide a vast amount of CO_2 Emissions affecting the environment. The materials considered in the detailed design calculations are the main construction materials that make 85% of the materials needed in a building which are Concrete, Bricks, and Steel, given their importance in the construction industry in Egypt and worldwide. In addition to that, all the additional building materials like Coarse aggregate, Fine aggregate, glass, and drywall were considered as a percentage of the total emissions produced from Concrete, Bricks, and Steel.

The detailed emissions calculations of the main construction materials include the total carbon emissions produced in the production and transportation for each one of these materials, through illustrating the comparison between the usage of conventional materials and sustainable materials and the difference in their Carbon emission savings. The construction phase methodology for computing the main materials emissions and savings was based on the present-day conventional and sustainable construction practices for high-rise buildings in Egypt and worldwide.

Firstly, the model carbon concrete emissions calculations were based on a comparison of Conventional and sustainable concrete with a strength of 50MPa, 60MPa, 70MPa, since it is a typical strength for High-Rise Buildings according to the literature review and the Egyptian code of building. Conventional and Sustainable concrete Mix Designs were developed based on the American Concrete Institute (ACI) and the Egyptian Code of Building (ECB). Conventional concrete Mix designs were developed, giving the strength of 50MPa, 60MPa, and 70MPa with a chemical Admixture of Superplasticizers of type A and F. On the other hand, sustainable concrete mix designs were developed with an addition of mineral admixtures of Slag Cement and Fly Ash. Fly Ash and Slag Cement minimize the cement amount in each concrete mix design, as cement is the largest producer of carbon emissions. The least producer of CO_2 Emissions in sustainable concrete was considered the most sustainable option. Besides that, Concrete transportation emissions were calculated based on ready mix concrete mixing trucks' diesel consumption and CO_2 emissions produced based on the average distance traveled, the total amounts of concrete needed for a high-rise building, and the number of trips taken to transport all the needed concrete amount.

Secondly, the model steel carbon emission calculations were based on the two main steel production methods, which are basic oxygen blast furnace and electric arc furnace, which both have been analyzed in reference to the energy used through the production of one steel Ton. The energy consumed is then converted to carbon emissions, indicating the extremely effective carbon emissions and energy Consumption production method. Besides that, Steel Transportation emissions were calculated based on trucks' diesel consumption and CO_2 emissions produced based on the average distance traveled. The total amounts of steel needed for a high-rise building and the number of trips taken to transport all the needed amount.

Finally, the model bricks carbon emissions calculations were based on three types of bricks which are: conventional Clay bricks, Concrete bricks, and Fly Ash Bricks. Conventional Clay Bricks were considered conventional as they are the most commonly used in Egypt, while Concrete and Fly Ash were considered the sustainable types due to the lower Carbon emissions produced in their production. The least producer of CO_2 Emissions was considered the most sustainable option. Besides that, brick Transportation emissions were calculated based on trucks' diesel consumption and CO_2 emissions produced based on the average distance traveled and the total amounts of bricks needed for a high-rise building, and the number of trips taken to transport all the needed amount.

Thus, the total carbon emissions savings are computed from all construction phase materials used for High-Rise Buildings in Egypt. The total savings were monetized to express the financial saving of reducing Carbon emissions.

3.2.2 MODEL OPERATIONAL PHASE DESIGN

The model operational phase design focuses on the main operational elements that consume high energy and produce high indirect carbon emissions and are found in all High-Rise building types. Based on the literature review, the elements were: Lights, Air Conditioners, Water heaters, and window glazing.

The model design is based on the selection, management, measurement, and analysis of operational elements which are more sustainable, providing fewer carbon emissions, in comparison to traditional operational elements that provide a vast amount of CO_2 Emissions affecting the environment. The operational elements considered in the detailed design calculations are the main operational elements that make most of the energy consumption in most high-rise building types needed. The detailed emissions calculations of the main operational elements include the total carbon emissions produced in the production and operation for each of these elements through illustrating the comparison between the usage of conventional elements and sustainable elements and the difference in their Carbon emission savings. The use-phase methodology for computing main operational elements emissions and savings were based on the present-day conventional and sustainable operating elements for high-rise buildings in Egypt and worldwide.

Firstly, the model lighting emissions calculations were based on a comparison of Conventional and sustainable light bulbs giving the same lumens. The conventional light bulbs were considered to be incandescent light bulbs as they are the most commonly used in Egypt, and the sustainable ones were considered to be compact fluorescent (CFL) and light-emitting diodes (LEDs). The least producer of CO_2 Emissions was considered the most sustainable option.

Secondly, the model Water Heater emissions calculations were based on a comparison of Conventional and sustainable Water heaters. The conventional Water Heaters were an electric storage water heater as they are the most commonly used in Egypt, and the sustainable ones were considered to be Tankless Gas Water Heater, and Tankless Electric Water Heaters The least producer of CO_2 Emissions was considered the most sustainable option.

Thirdly, the model Air Conditioner emissions calculations were based on a comparison of Conventional and sustainable air conditioners giving the same cooling tons. The conventional Air Conditioners were considered to be Split Air Conditioners as they are the most commonly used in Egypt, and the sustainable ones were considered to be Air Cooled Chilled Water AC systems and Water-Cooled Chilled water AC systems. The least producer of CO_2 Emissions was considered the most sustainable option.

Finally, the model Window glazing emissions calculations were based on a comparison of Conventional and sustainable window glazing. The conventional Single window glazing are the most commonly used in Egypt, and the sustainable ones were considered to be double window glazing. The least producer of CO_2 Emissions was considered the most sustainable option.

Thus, the total carbon emissions savings are computed from all use-phase elements used for High-Rise Buildings in Egypt. The total savings were monetized to express the financial saving of reducing Carbon emissions.

3.3 MODEL COMPARISON AGAINST COMMERCIAL LIFE CYCLE ANALYSIS MODELS

The High-Rise Carbon Emission model developed and proposed in this study provides a different role, functionality, goal, and aim compared to what is offered by Commercial life cycle analysis software “Gabi”. Reference to the Literature Review GaBi Software focus is to provide a detailed calculation of carbon emissions based on life-cycle analysis for mainly manufactured products. GaBi Software is more dynamic and customizable for product manufacturers and designers to assess their product sustainability within the production or manufacturing cycle. However, this flexible, detailed assessment comes at the expense of the user-friendliness of the software interface making the program need extensive training before using targeting more the qualified professionals to fully benefit from GaBi Software. In addition to that, GaBi Software only assesses sustainability references to manufactured product inputs. Besides that, Use-Phase elements are not considered in the GaBi Software assessment, as you can evaluate the sustainability of manufacturing a light bulb and not its operational consumption of energy and emissions impacts. Therefore, the proposed model focuses on limiting the shortcomings of this Platforms by providing a dynamic, user-friendly interface focusing on High-Rise buildings allowing users with different knowledge backgrounds to use it. In addition to that, the model focuses on the Construction Phase in Life Cycle analysis in the production and transportation of the Construction Material, and in the Use-Phase it provides detailed assessment based not only on life cycle analysis but on the daily energy consumption, which is considered to be with crucial significance to High-Rise Buildings sustainability analysis.

3.4 MODEL DATA COLLECTION

3.4.1 MODEL CONSTRUCTION PHASE DATA

Through the development of the construction phase of the model, difficulties have been encountered due to the abundance of data regarding carbon emissions in Egypt from Concrete, Steel, Bricks, and their transportation. Therefore, carbon Emissions data have been obtained from the USA Southern States like southern California and Florida, which have similar weather conditions to Egypt.

In addition to that, the manufacturing process for Concrete, Bricks, and steel are considered to a large extend similar nevertheless geographic location; thus, the model can depend on data from different geographic locations worldwide. Besides that, reference to the literature data on Carbon Emission savings were obtained as follows:

1. Concrete: high Strength Concrete Mix designs were developed for the model based on the Egyptian Code of Building (ECB) and American Concrete Institute (ACI) guide number ACI 211.4R "Guide for Selecting Proportions for High-Strength Concrete Using Portland Cement and Other Cementitious Materials on different concrete". The Detailed Mix Design for each concrete Mixture used in the investigation can be found in Appendix I. Nevertheless, the Mix Design guides, and the research developed concrete mixtures illustrate the impact of mineral admixtures and cement reduction, leading to a carbon emission saving as cement is considered the main driver of Carbon Emissions in the construction industry. In addition to that, Carbon Emissions Cement Production factors were considered based on a report developed in 2016 on Low-Carbon Roadmap for the Egyptian Cement Industry by European Bank for Reconstruction and Development (EBRD), which identified the Cement Carbon Emissions factors in Egypt in 2020 to be 820 kg CO_2 /Ton Cement. In addition to that, according to the US Department of energy in 2007, the Financial Cost Saving of Carbon Emission in 2020 is 43.3 dollars per ton (Vanderborg et al., 2016).

2. Steel: In the Model, the quantity of steel in structural elements is estimated based on the regression model function of structural element volume, which was developed in reference to a study from Hail University on "preliminary estimate for reinforcement steel quantity in residential buildings" (Mahamid, 2016). In addition to that, Carbon Emission Factors were based on two studies, one commissioned by world steel association and the other by EVRAZ (British multinational vertically integrated steel making and mining company). Both studies showed two manufacturing processes both in the USA and Canada, which are conventional blast oxygen furnace and sustainable electric arc Furnace and their energy consumption and Carbon Emissions (World Steel Association, 2018). For blast furnace-basic oxygen furnace Carbon emission factor 2081 kg CO_2 / Ton Steel and for electric arc Furnace 441 kg CO_2 / Ton (EVRAZ, 2016).

3. Bricks: The model calculates the number of bricks on each floor by dividing one brick volume by the net wall volume after removing windows. In addition to that, Carbon emissions were calculated based on a study published by Chusid, which introduces the use of sustainable bricks like fly ash bricks and Concrete bricks in comparison to conventional clay bricks and their production energy consumption and carbon emissions. For Clay bricks, the Carbon emissions factor 0.59 CO_2 / brick. For Concrete bricks, the carbon emission factor 0.34 CO_2 / brick, and for fly ash bricks, the carbon emission factor 0.11 CO_2 / brick (Chusid et al., 2009).

4. Transportation: The model considers transportation carbon emission in each of Concrete, Bricks, and steel. Besides that, Carbon Emissions were calculated based on a study from the United States Environmental Protection Agency on carbon emission factors for several kinds of vehicles with different fuel types. For the Concrete mixing truck, the Carbon Emission factor was considered 0.9 CO_2 kg/ km Travelled, and for Steel and Brick's heavy-duty trucks were considered with 1.45 CO_2 kg/ km Travelled (EPA, 2014). In addition to that, Material truck loading capacity was considered for each material. For ready mix concrete, the truck capacity was nine cubic meters. (Construction Equipment, 2020), Steel loading truck capacity and weight were for 20 tons of steel. (Fess Transport, 2020), and Brick's loading truck capacity was ten cubic meters. (Fess Transport, 2020)

3.4.2 MODEL OPERATIONAL DATA

Through the development of the operational phase of the model, similar difficulties to the construction phase have been tackled due to the lack of data regarding carbon emissions in Egypt for the main operational equipment, which are Light Bulbs, AC, Water Heaters, and window glazing. Therefore, carbon Emissions data have been obtained from the USA Southern States like southern California and Florida, which have similar weather conditions to Egypt.

1. For Light Bulbs

   The model calculates carbon emissions based on a study published by Energy Rating and Energy Star for sustainable light bulbs like fluorescent (CFL) or light-emitting diodes (LEDs) in comparison to conventional incandescent bulbs. The Comparison include each light bulb type operational energy consumption and carbon emissions. In addition to that, the comparison is based on giving the same number of Lumens with the lowest possible energy consumption and carbon emissions. For incandescent bulbs, carbon emissions based on operational energy consumption of 8 hours annually was 152.42 CO_2 kg per Number of light Bulbs. For fluorescent (CFL) carbon emissions factor based on operational energy consumption of 8 hours annually was 34.93 CO_2 kg per number of light Bulbs, and light-emitting diodes (LEDs) carbon emissions factor based on operational energy consumption of 8 hours annually was 22.23 CO_2 kg per number of light Bulbs (Energy Rating, 2020).

2. For Air Conditioner

   The Model calculates all AC types of annual operation energy consumption and Carbon emissions reference to the assumption of 12-hour daily operation of AC based on Egypt's Annual weather. The model initially calculates the cooling tons needed to be based on the floor area by the cooling tons obtained (Engineering Pro Guides, 2019), the model calculates the Watts needed of each Air Conditioner based on each type of energy consumption. In addition to that, the Model calculates carbon emissions for sustainable Air conditioners like Air Cooled Chilled water AC system and water-cooled chilled water AC system in comparison to Egypt regular used Split Units system ACs. Besides that, the energy consumption for each AC system for Split AC system energy consumption is 35.89 Watt per Hour, For Air Cooled Chilled water AC System energy consumption is 28.70 Watt per Hour and water-cooled chilled water AC System is 16.75 Watt per Hour. Therefore, the carbon emission factor for each AC reference to a study made by Engineering Pro Guides for Split AC system, Air Cooled Chilled water AC system, and water-cooled chilled water AC system is 0.000417305 kg CO_2 per Watt (Engineering Pro Guides, 2019).

3. For Water Heaters

The Model calculates all Water Heater types of annual operation energy consumption and Carbon emissions reference to the assumption of 8-hour daily operation for Storage based water heaters and 4-hour daily operation for Tankless water heaters. The model calculates the Watts or BTU needed of each water heater based on each type of energy consumption or gas consumption. Based on that, the Model calculates carbon emissions reference to a study published by Energy Saver for sustainable water heaters like tankless electrical water heaters and tankless gas water heaters in comparison to Egypt regular used electrical storage water heaters. Besides that, the electrical consumption or gas consumption for each water heater reference to a study made by Energy Saver is for electrical storage water heaters energy consumption is 2500 Watt per Hour, for electrical tankless water heaters energy consumption is 4500Watt per Hour, tankless gas water heater gas consumption is 41000 BTU per Hour. Therefore, the carbon emission factor for each water heater reference to a study made by Energy Saver for the electrical storage water heater is 256 CO_2 kg / GJ, the electric tankless water heater is 243 CO_2 kg per GJ, and Tankless gas water heater is 63.6 kg CO_2 per GJ (Energy Saver, n.d.)

4. For Window Glazing

Based on a study conducted by Amirkhani shows that double window glazing reduces AC CO_2 emissions by 5%. Therefore, in the model, a comparison has been made between the traditional single window glazing and sustainable double glazing (Amirkhani et al., 2019).

3.5 METHODOLOGICAL ASSUMPTIONS

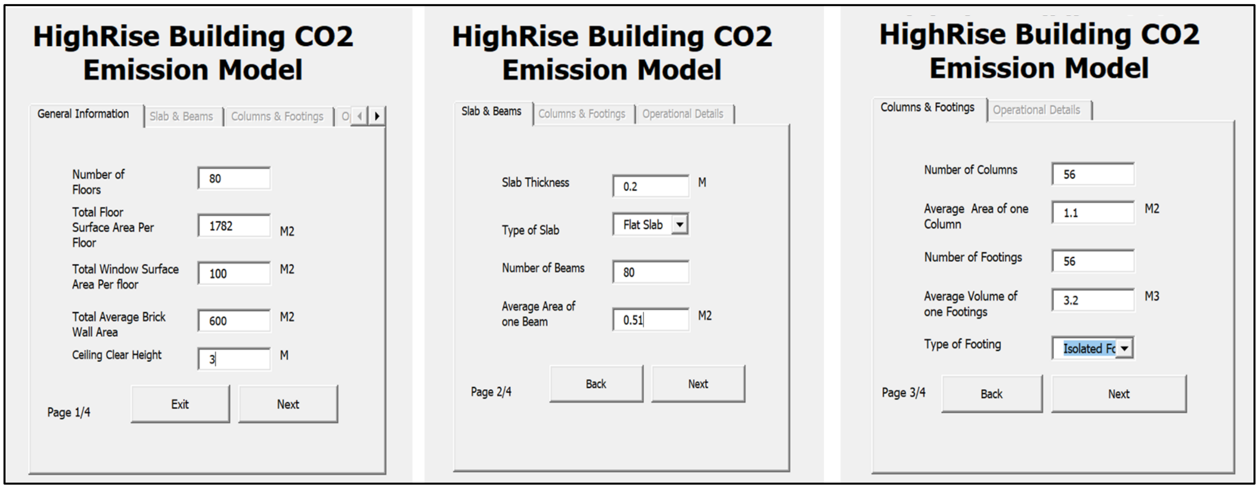
The model was created based on several assumptions for the construction phase and use-Phase. The assumption was made to be based on the most realistic conditions, calculations, and outputs to serve the situation in Egypt. However, the readers of this work are encouraged to challenge, redefine, and validate these assumptions.

3.5.1 MODEL CONSTRUCTION PHASE ASSUMPTIONS

Several Construction related hypotheses were considered based on the set up of a standard international high-rise building based on the Case study of the Empire state building, The Burj Khalifa, Egyptian code of building and inspired by h.kimura journal on " Structural Design of 80-Story RC High-Rise Building Using 200 MPa Ultra-High-Strength Concrete ".

The model construction phase assumptions aim to justify the average transportation distance to the construction site amounts of material needed such as Concrete, steel, and bricks.

The model assumptions were all made based on the typical design of high-rise buildings according to the mentioned above references, which have been concluded from a typical high-rise building. In addition to that, the model is dynamic, and all the below are inputs by the user of the Model. The figure 3-2 and figure 3-3 illustrates the model interface.



Number of Floors: 80
Total Floor Surface Area Per Floor: 1782 M2
Total Window Surface Area Per floor: 100 M2
Total Average Brick Wall Area: 600 M2
Ceiling Clear Height: 3 M

Slab Thickness: 0.2 M
Type of Slab: Flat Slab
Number of Beams: 80
Average Area of one Beam: 0.51 M2

Number of Columns: 56
Average Area of one Column: 1.1 M2
Number of Footings: 56
Average Volume of one Footings: 3.2 M3
Type of Footing: Isolated Fc

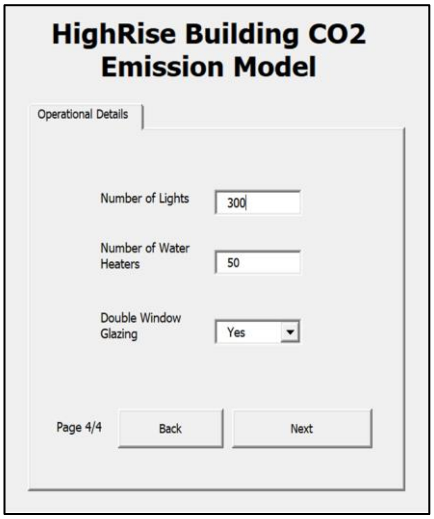
Figure 3-2: Model Construction Phase User Interface

We will assume an average High-rise building which composed of:

1. Number of floors: Eighty stories
2. Total Floor Surface area per floor: 1,782 M2
3. Total Window Surface Area per floor 100 m2
4. Total Average Brick wall area per floor 600 m2
5. brick dimensions: 0.25 x 0.12 x 0.6 Meters
6. brick weight: 2.5 kg
7. Clear height: 3 m
8. Aggregate density: 1750 kg/m3
9. Slab Thickness: 0.20cm
10. Slab Type: Flat Slab
11. Number of Beams: 80
12. Average Area of one Beam: 0.51m2
13. Number of Columns: 56 Columns
14. Average Area of one column: 1.1 m2
15. Number of Footings: 56 Footings

16. Average Volume of footings: 3.2m3
17. Type of footing used: Isolated footings.
18. Concrete strength will be assumed to be 50MPa, 60MPa, and 70 MPa.
19. Average round trip distance traveled for material transportation: 30 km.

3.5.1 MODEL OPERATIONAL PHASE ASSUMPTIONS



HighRise Building CO2 Emission Model

Number of Lights: 300

Number of Water Heaters: 50

Double Window Glazing: Yes

Figure 3-3: Model Operational Phase User Interface

The Use-Phase assumptions were mainly used on the operational elements within high-rise building offices or apartments. The use-phase assumptions include:

Lighting and Electrical Appliances in each Floor average:

- Light Bulbs per floor = 300 per floor with daily operation of 8 hours
- Air Conditioners per floor = based on surface area and cooling ton, and daily operation of 12 hours was assumed.
- Water Heaters per floor = 50 with daily operation of 4 hours for tankless water heaters and 8 hours for storage water heaters.
- Number of water heaters are considered zero in case of use of solar water heaters emissions are zero.
- Window Glazing Availability: Yes

3.5.2 Model Financial Assumptions

The aim of this investigation is to identify the carbon dioxide savings in terms of tons. However, such quantification is complex to define; hence, a monetary value will be used to define it more. Such monetary value is based on the Social Cost of Carbon (SCC) Concept, which is defined as the estimate of monetized damages caused by the increase of carbon dioxide emissions which led to a deterioration in the natural habitat, wildlife, human health, damage of property due to climate change and risk of floods, and agriculture damage. SCC was defined by the US Department of energy in 2007 to be Thirty-three dollars per ton with an increase of 2.4% annually. In 2020 the SCC was 43.3 dollars per ton (Department of Energy, 2010).

3.6 MODEL CALCULATIONS

The model calculations are created to illustrate and evaluate the differences in carbon footprint for Traditional and Sustainable Mixed-use High-rise buildings. All calculations are built on the methodological assumptions mentioned in section 3.4.

3.6.1 MODEL CONSTRUCTION PHASE CALCULATIONS

The Model construction calculations aim to calculate carbon emissions produced from concrete, steel, bricks, and other types of materials merged. Through this subsection, the sequence of the calculations of each material will be elaborated based on the methodological assumptions obtained in section 3.5.

Calculations of Concrete CO_2 Emissions:

Model Inputs:

1. Input each Concrete structural element volume and area.
2. Input total number of each Concrete structural element.

Model Calculations

1. The model processes the inputs for both traditional and sustainable mix designs, calculating the emissions caused in the production of cement as cement is one of the major CO_2 emission producers based on the literature. Water, course, and fine aggregates as their emissions are considered negligible.

2. The Cement CO_2 discharges are calculated by multiplying the CO_2 emission factor from the literature and the total volume of cement required for each concrete mix design.

Model Equations

1. Total volume of concrete (m^3) = User Input Number of each concrete element x User Input Area of one element per floor x User Input Height per floor
2. Total Cement weight (ton) = Cement (kg/m^3) x Total Volume of Concrete (m^3) x 0.001; reference to the Mix Design Appendix I
3. Total Cement CO_2 Emissions (kg) = Cement CO_2 Emissions Factor x Cement (ton)
    - Cement CO2 Emissions factor (kg CO2 / ton Cement) = 820 (Vanderborg et al., 2016)
4. CO_2 Emissions Savings (kg) = Sustainable Mix Design CO_2 Emissions (kg) – Traditional Mix Design CO_2 Emissions (kg)
5. CO_2 Emissions Savings (%) =

$$\frac{\text{Sustainable Mix Design CO2 Emissions (kg)} - \text{Traditional Mix Design CO2 Emissions (kg)}}{\text{Traditional Mix Design CO2 Emissions (kg)}}$$

6. Cost Saving (US Dollars \$) = $\frac{\text{CO2 Emissions Savings (kg)}}{1000}$ x Financial Cost Saving of Carbon Emission in 2020. Reference to US Department of Energy (Department of Energy, 2010)

Model Output

1. Ultimately, the model demonstrates the comparison for both traditional and sustainable approaches identifying the possible savings that can be reached when shifting from the traditional to the sustainable method.
2. The model is implemented on an 80-story High-rise building; however, it is a dynamic model in which it can be implemented on any High-rise building within Egypt.

Calculations of Steel CO_2 Emissions:

Model Inputs:

1. Input each Concrete structural element volume and area.
2. Input total number of each Concrete structural element.

Model Calculations

The model processes the inputs for both traditional and sustainable production lines, which were defined by the literature as basic oxygen furnace and electric arc furnace. The Carbon Discharges are computed by multiplying the total steel weight by the energy consumed by the emission factor per energy consumed for each production line.

Model Equations

1. Total volume of each structural element = User Input Number of each structural element x User Input Area of one element per floor x User Input Height per floor
2. All the below equations are Regression model functions of structural elements volume which were developed in reference to a study from Hail University on “preliminary estimate for reinforcement steel quantity in residential buildings” (Mahamid, 2016).
   - Average Steel (ton) in columns equation = 124.13 x Total Column Volume
   - Average Steel (ton) in Beam’s equation = 100.42 x Total Beam Volume
   - Average Steel (ton) in Isolated Footings equation = 75.16 x Total Footings Volume
   - Average Steel (ton) in Strip Footings equation = 90.58 x Total Footings Volume
   - Average Steel (ton) in Flat Slab equation = 92.25 x Total Slab Volume
   - Average Steel (ton) in Hollow Block Slab Equation 122.36 x Total Slab Volume
3. Total Weight of Steel (ton) = Sum of all elements weights (ton)
4. Total Steel CO_2 Emissions (kg) = Steel CO_2 Emissions Factor for each Production method x total Steel weight (ton)
   - Blast furnace-basic oxygen furnace CO_2 Emissions factor (kg CO_2 / ton steel) = 2081 (EVRAZ, 2016)
   - Electric Arc furnace CO_2 Emissions factor (kg CO_2 / ton steel) = 441 (EVRAZ, 2016)
5. CO_2 Emissions Savings (kg) = Electric Arc Furnace Production Method emissions (kg) – Traditional Blast furnace production Method emissions (kg)
6. CO_2 Emissions Savings (%) =

$$\frac{\text{Electric Arc Furnace Production Method emissions (kg)} - \text{Traditional Blast furnace production Method emissions (kg)}}{\text{Traditional Blast furnace production Method emissions (kg)}}$$

7. Cost Saving (US Dollars \$) = $\frac{\text{CO2 Emissions Savings (kg)}}{1000}$ x Financial Cost Saving of Carbon Emission in 2020. Reference to US Department of Energy (Department of Energy, 2010)

Model Output

1. Ultimately, the model demonstrates the comparison for both traditional and sustainable approaches identifying the possible savings that can be reached when shifting from the traditional to the sustainable method.
2. The model is implemented on an 80-story High-rise building; however, it is a dynamic model in which it can be implemented on any High-rise building within Egypt.

Calculations of Brick Emissions:

Model Inputs:

1. Input total brick wall area for each floor
2. Input Total window surface area for each floor

Model Calculations

The model processes the inputs for both traditional and sustainable brick types, which were defined by the literature as sustainable concrete bricks, sustainable Fly ash bricks, and Traditional clay bricks. The carbon discharges are computed by multiplying the overall number of bricks used with the carbon emission factor for each production line based on the brick type, which is identified in the literature.

Model Equations

1. Area of one brick (m^2) = 0.25 x 0.125 = 0.03125 (m^2)
2. Total brick wall area without windows (m^2) = User input Total average brick wall area (m^2) per floor – User input Total Window surface Area per Floor (m^2)
3. Total Average Number of Bricks = $\frac{\text{Total brick wall area without windows (m2)}}{\text{Area of one brick (m2)}}$
4. Total Bricks CO_2 Emissions (kg) = Bricks CO_2 Emissions Factor for each brick type x total Steel weight (ton).
    - Clay Bricks CO_2 Emissions factor (CO_2 / brick) = 0.59 (Chusid et al., 2009)
    - Concrete Bricks CO_2 Emissions factor (CO_2 / brick) = 0.34 (Chusid et al., 2009)

- Fly Ash Bricks CO_2 Emissions factor (CO_2 / brick) = 0.11 (Chusid et al., 2009)

5. CO_2 Emissions Savings (kg) = Sustainable brick type emissions (kg) – Conventional brick type emissions (kg)
6. CO_2 Emissions Savings (%) =
$$\frac{\text{Sustainble Brick type emissions (kg)– Conventional brick type emissions (kg)}}{\text{Conventional production Method emissions (kg)}}$$
7. Cost Saving (US Dollars $) = $\frac{\text{CO2 Emissions Savings (kg)}}{1000}$ x Financial Cost Saving of Carbon Emission in 2020. Reference to US Department of Energy (Department of Energy, 2010)

Model Output

1. Ultimately, the model demonstrates the comparison for both traditional and sustainable approaches identifying the possible savings that can be reached when shifting from the traditional to the sustainable method.
2. The model is implemented on an 80-story High-rise building; however, it is a dynamic model in which it can be implemented on any High-rise building within Egypt.

Calculations of Transportation Emissions:

Model Inputs:

Average distance travelled for transportation is considered to be 30 km.

Model Calculations

The transportation emissions are calculated by identifying the number of Concrete, Steel, or bricks truckloads needed to provide the needed material to the site. The total number of truckloads needed is multiplied by the total round-trip distance traveled multiplied by the diesel consumption per truckload, which is identified in the literature, multiplied by the diesel consumption emission factor, which is identified in the literature.

Model Equations

1. No. of truck loads = $\frac{\text{Average Volume or weight of material}}{\text{Truck Capacity}}$
2. Concrete Mixing Truck Capacity = 9 m^3 truck capacity (EPA, 2014).
3. Bricks Truck Capacity = 10 m^3 truck capacity (EPA, 2014).
4. Steel Truck Capacity = 20 tons truck capacity (EPA, 2014).

5. Total Truck Distance travelled = Average round trip distance (km) x No. Truck Loads
    - Concrete truck Diesel CO_2 Emissions Factor (kg/km) = 0.905 (Construction Equipment, 2020)
    - Bricks truck Diesel CO_2 Emissions Factor (kg/km) = 1.456 (Fess Transport, 2020)
    - Steel truck Diesel CO_2 Emissions Factor (kg/km) = 1.456 (Fess Transport, 2020)

Model Output

Thus, the model adds the transportation emissions for transporting Concrete, Bricks, and steel in the comparison for both traditional and sustainable approaches identifying the possible savings that can be reached in a more realistic approach.

3.6.2 MODEL OPERATIONAL PHASE CALCULATIONS

The Operational calculations focus on the emissions caused by any operational building-related elements like light, electrical appliances, window glazing, and window shading. The assumptions were made based on earlier discussed methodological assumptions.

Calculations of Light CO_2 Emissions:

Model Inputs:

1. Input total number of lights bulbs required for operation.
2. The transportation emissions are considered negligible, so they will not be considered.

Model Equations:

1. Total Light Bulbs CO_2 Emissions (kg) = Light Bulbs CO_2 Emissions Factor for each Light bulb type x User input total number of light bulbs
    - Incandescent bulbs CO_2 Emissions factor (kg CO_2 / Light Bulb) = 152.42 (Energy Rating, 2020)
    - Compact Fluorescent light (CFL) bulbs CO_2 Emissions factor (kg CO_2 / Light Bulb) = 34.93 (Energy Rating, 2020)
    - light-emitting diodes (LED) bulbs CO_2 Emissions factor (kg CO_2 / Light Bulb) = 22.23 (Energy Rating, 2020)

2. CO_2 Emissions Savings (kg) = Sustainable Light Bulbs type emissions (kg) – Conventional Light Bulbs type emissions (kg)
3. CO_2 Emissions Savings (%) =
$$\frac{\text{Sustainable Light Bulbs type emissions (kg)} - \text{Conventional Light Bulbs type emissions (kg)}}{\text{Conventional Light Bulbs type emissions (kg)}}$$
4. Cost Saving (US Dollars \$) = $\frac{\text{CO2 Emissions Savings (kg)}}{1000}$ x Financial Cost Saving of Carbon Emission in 2020. Reference to US Department of Energy (Department of Energy, 2010)

Model Calculations

1. The model processes the inputs for both traditional and sustainable light bulbs, which were defined by the literature as Compact fluorescent light (CFL) or light-emitting diodes (LEDs), or incandescent bulbs. The carbon discharges are computed by multiplying the overall number of light bulbs by the annual CO_2 emissions for each light bulb based on the literature.

Model Output

1. Ultimately, the model demonstrates the comparison for both traditional and sustainable approaches identifying the possible savings that can be reached when shifting from the traditional to the sustainable method.
2. The model reflects annual usage and 50 years of usage.
3. The model is implemented on an 80-story High-rise building; however, it is a dynamic model in which it can be implemented on any High-rise building within Egypt.

Calculations of Water Heaters CO_2 Emissions:

Model Inputs:

1. Input total number of Water heaters and Air Conditioners.
2. The transportation emissions are considered negligible, so they will not be considered.

Model Calculations

The model processes the inputs for both traditional and sustainable Water heaters and Air Conditioners, which were defined by the literature as electric water heaters, gas water heaters, and air conditioners. The carbon discharges are computed by multiplying the overall number of water heaters or air conditioners by the annual energy consumption by the energy CO_2 emissions factor for each electrical appliance based on the literature.

Model Equations:

1. Total Number of units = User input
2. Total water heater CO_2 Emissions (kg) = total number of water heaters x type of water heater gas or electrical consumption per hour x operational hours x CO_2 Emissions Factor for each water heater type.
   - Electrical Storage water heater electrical consumption per hour = 2,500 watt/hr, Unit conversions watt to GJ/hr = 0.009, Average Operational hours = 8 Hours, CO_2 Emissions Factor (kg/GJ) = 256 (Energy Saver, n.d.)
   - Electrical tankless water heater electrical consumption per hour = 4,500 watt/hr, Unit conversions watt to GJ/hr = 0.0162, Average Operational hours = 4 Hours, CO_2 Emissions Factor (kg/GJ) = 243 (Energy Saver, n.d.)
   - Gas tankless water heater gas consumption per hour = 41,000 BTU, Conversions watt to GJ/hr = 0.0432591, Average Operational hours = 4 Hours, CO_2 Emissions Factor (kg/GJ) = 63.6 (Energy Saver, n.d.)
3. CO_2 Emissions Savings (kg) = Sustainable water heater type emissions (kg) – Conventional water heater type emissions (kg)
4. CO_2 Emissions Savings (%) =

$$\frac{\text{Sustainable water heater type emissions (kg)} - \text{Conventional water heater type emissions (kg)}}{\text{Conventional water heater type emissions (kg)}}$$

5. Cost Saving (US Dollars \$) = $\frac{\text{CO2 Emissions Savings (kg)}}{1000}$ x Financial Cost Saving of Carbon Emission in 2020. Reference to US Department of Energy (Department of Energy, 2010)

Model Output

1. Ultimately, the model demonstrates the comparison for both traditional and sustainable approaches identifying the possible savings that can be reached when shifting from the traditional to the sustainable method.
2. The model reflects annual usage and 50 years of usage.
3. The model is implemented on an 80-story High-rise building; however, it is a dynamic model in which it can be implemented on any High-rise building within Egypt.

Calculations of Air Conditioning systems CO_2 Emissions:

Model Inputs:

1. Input total number of Water heaters and Air Conditioners.
2. The transportation emissions are considered negligible, so they will not be considered.

Model Calculations

The model processes the inputs for both traditional and sustainable Water heaters and Air Conditioners, which were defined by the literature as electric water heaters, gas water heaters, and air conditioners. The carbon discharges are computed by multiplying the overall number of water heaters or air conditioners by the annual energy consumption by the energy CO_2 emissions factor for each electrical appliance based on the literature.

Model Equations

1. Total Area of Building (m^2) = User Input Area of one floor x User Input total no. of stories
2. Cooling tons required = $\frac{\text{Total Area of Building } (m^2)}{41.8}$ (Engineering Pro Guides, 2019).
3. Total AC CO_2 Emissions (kg) = Electrical consumption for Each AC type x operational hours x CO_2 Emissions Factor for AC.
    - Electrical consumption for Split AC (watt / hr) = 1.5 x Cooling tons required x 1000 (Engineering Pro Guides, 2019).
    - Electrical consumption for Air Cooling chilled water AC (watt / hr) = 1.2 x Cooling tons required x 1000 (Engineering Pro Guides, 2019).
    - Electrical consumption for Water Cooling chilled water AC (watt / hr) = 0.7 x Cooling tons required x 1000 (Engineering Pro Guides, 2019).
    - CO_2 Emissions Factor (kg/watt) = 0.000417305 (Engineering Pro Guides, 2019).
4. CO_2 Emissions Savings (kg) = Sustainable AC type emissions (kg) – Conventional AC type emissions (kg)
5. CO_2 Emissions Savings (%) =

$$\frac{\text{Sustainable AC type emissions (kg)} - \text{Conventional AC type emissions (kg)}}{\text{Conventional water heater type emissions (kg)}}$$

6. Cost Saving (US Dollars \$) = $\frac{\text{CO2 Emissions Savings (kg)}}{1000}$ x Financial Cost Saving of Carbon Emission in 2020. Reference to US Department of Energy (Department of Energy, 2010)

Model Output

1. Ultimately, the model demonstrates the comparison for both traditional and sustainable approaches identifying the possible savings that can be reached when shifting from the traditional to the sustainable method.
2. The model reflects annual usage and 50 years of usage.
3. The model is implemented on an 80-story High-rise building; however, it is a dynamic model in which it can be implemented on any High-rise building within Egypt.

Calculations of Window glazing emissions:

Model Inputs:

1. Input average total area of windows.
2. Input if window glazing is used or not.
3. The transportation emissions are considered negligible, so they will not be considered.

Model Calculations

1. The model processes the inputs for both traditional and sustainable window glazing, which were defined by the literature as traditional single window glazing and sustainable double low emission window glazing.
2. Based on the literature, double glazing reduces 5% of the required cooling load in each room.
3. The Emissions reduction and energy saving are computed by multiplying the total number of AC units with the overall number of AC unit energy saving by the CO_2 emission factor.
4. The Emissions are calculated by multiplying the total number of low emission double window glazing areas by the CO_2 emission saving factor.

Model Calculations

1. Total Window Glazing Saving = Total AC CO_2 Emissions (kg) x 0.05 (Amirkhani et al., 2019).

2. CO_2 Emissions Savings (kg) = Sustainable AC type emissions (kg) – Conventional AC type emissions (kg)
3. CO_2 Emissions Savings (%) =
$$\frac{\text{Sustainable AC type emissions (kg)} - \text{Conventional AC type emissions (kg)}}{\text{Conventional water heater type emissions (kg)}}$$
4. Cost Saving (US Dollars \$) = $\frac{\text{CO2 Emissions Savings (kg)}}{1000}$ x Financial Cost Saving of Carbon Emission in 2020. Reference to US Department of Energy (Department of Energy, 2010).

Model Output

1. Ultimately, the model demonstrates the comparison for both traditional and sustainable approaches identifying the possible savings that can be reached when shifting from the traditional to the sustainable method.
2. The model reflects annual usage and 50 years of usage.
3. The model is implemented on an 80-story High-rise building; however, it is a dynamic model in which it can be implemented on any High-rise building within Egypt.

CHAPTER 4

RESULTS AND ANALYSIS

4.1 INTRODUCTION

This section of the work summarizes the key findings and outcomes of the model, emphasizing the most influential outcomes in terms of carbon emission savings. However, the quantitative model finding must be interpreted with caution as they are based on several assumptions serving the true purpose of the model, which is delivering a framework to be disputed, tested, and challenged by researchers and practitioners in various fields across the world. Besides that, the model outcomes emphasis the paramount importance of sustainable practices in high-rise buildings construction and operation in comparison to conventional methods, which can be used as a proxy for prospective carbon emission saving and promoting the use of such sustainable practices in the construction industry in Egypt and across the world.

4.2 CONSTRUCTION PHASE MODEL OUTCOMES

Carbon emissions for the construction phase were computed for the major materials, which include Concrete, Steel, bricks, and material transportation emissions. Quantitative comparative analysis for carbon emission was conducted for each material using conventional methods and sustainable methods. Correspondingly carbon saving was computed as the difference between both.

4.2.1 CONCRETE MODEL OUTCOMES

The concrete carbon discharges and potential savings of conventional concrete mix for 50 MPa, 60 MPa, and 70Mpa in comparison to sustainable concrete mixes of Fly Ash and Slag cement respectively with the same compressive strength are illustrated below in the figures 4-1 to 4-8, and tables 4-1 to 4-4 correspondingly.

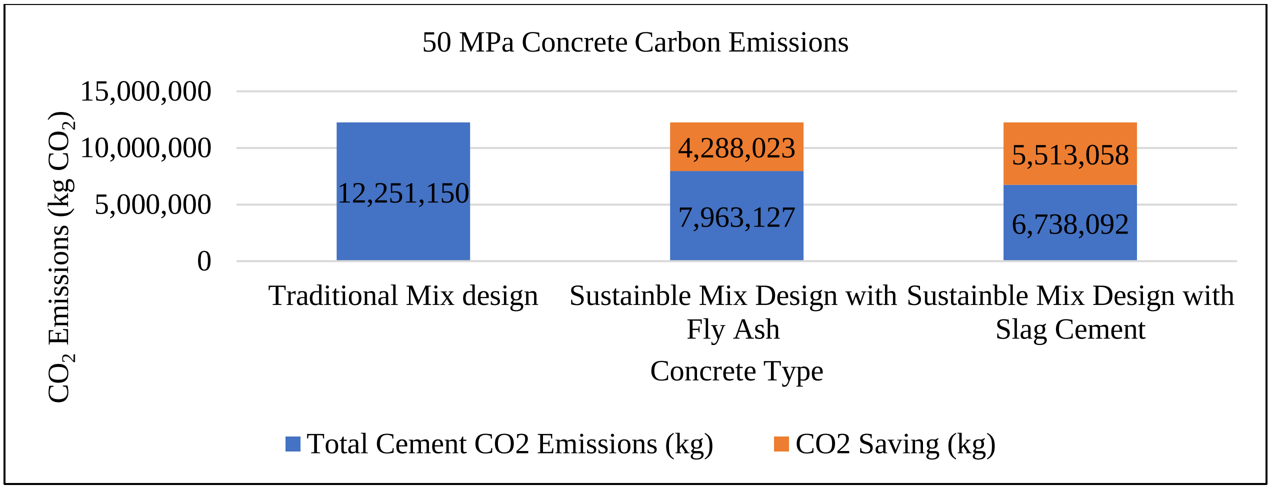


Figure 4-1: 50 MPa Concrete CO_2 emission

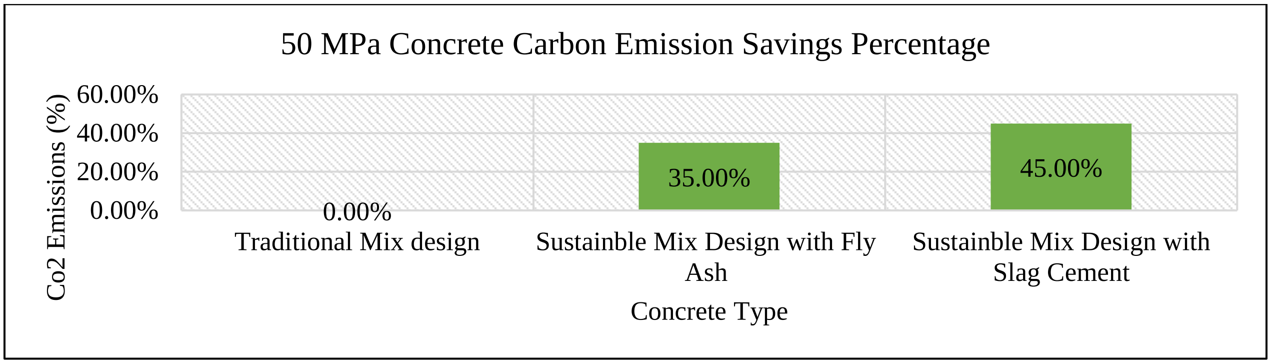


Figure 4-2: 50 MPa Concrete CO_2 Savings %

Table 4-1: 50 MPa Concrete Mix Designs and Carbon Emission Savings

Concrete			
M50 Concrete	Traditional Mix design	Sustainable Mix Design with Fly Ash	Sustainable Mix Design with Slag Cement
Total Volume in M3	32,740	32,740	32,740
Cement in tons	14,940	9,711	8,217
Cement CO_2 Emission factor in Egypt 2020 kg CO_2 per ton cement.	820		
Total Cement CO_2 Emissions (kg CO_2)	12,251,150	7,963,127	6,738,092
CO_2 Saving (kg CO_2)	0	4,288,023	5,513,058
CO_2 Savings %	0.00%	35.00%	45.00%
Cost Saving US Dollars $	$0	$185,671	$238,715

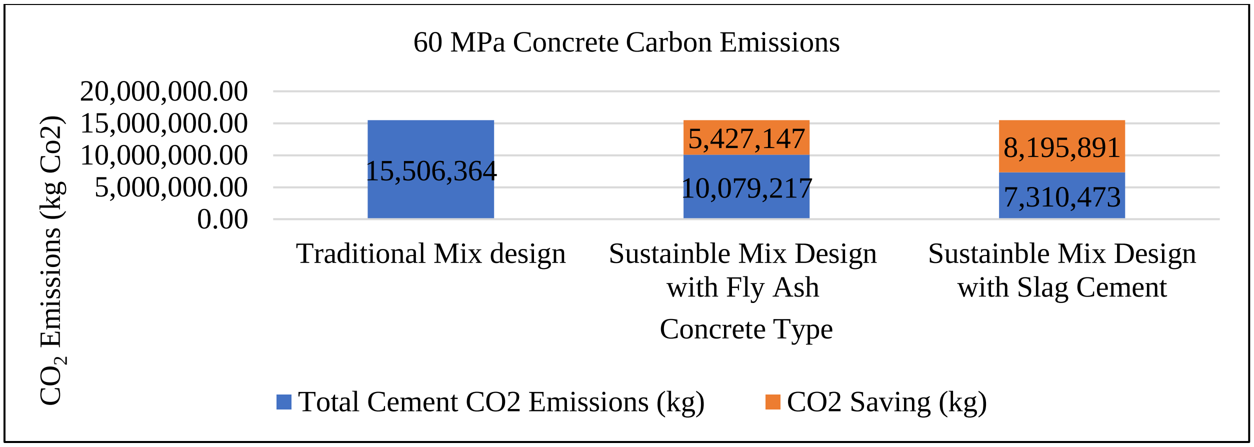


Figure 4-3: 60 MPa Concrete CO_2 Emissions

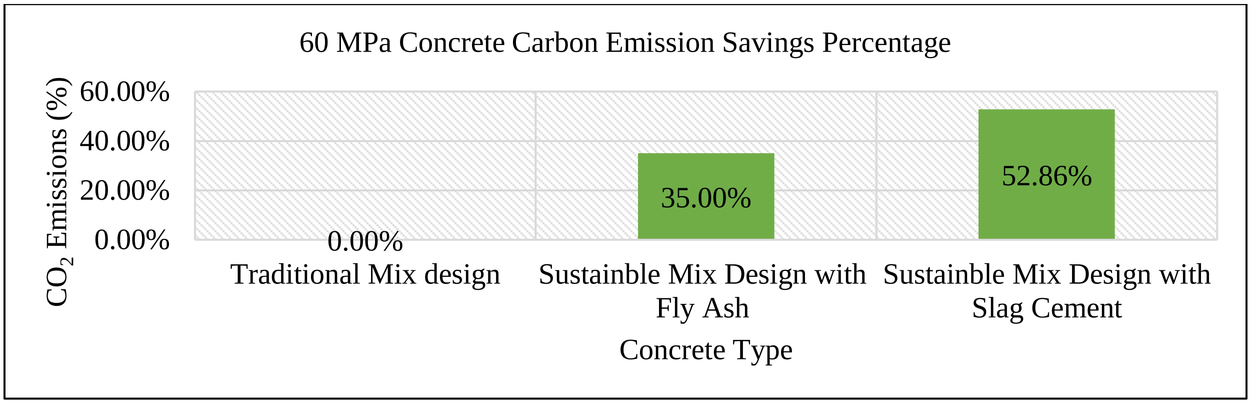


Figure 4-4: 60 MPa Concrete CO_2 Savings Percentage

Table 4-2: 60 MPa Concrete Mix Designs and Carbon Emission Savings

Concrete			
M60 Concrete	Traditional Mix design	Sustainable Mix Design with Fly Ash	Sustainable Mix Design with Slag Cement
Total Volume in M3	32,740	32,740	32,740
Cement in tons	18,910	12,292	8,915
Cement CO_2 Emission factor in Egypt 2020 kg CO_2 per ton cement.	820		
Total Cement CO_2 Emissions (kg CO_2)	15,506,364	10,079,217	7,310,473
CO_2 Saving (kg CO_2)	0	5,427,147	8,195,891
CO_2 Savings %	0.00%	35.00%	52.86%
Cost Saving US Dollars $	$0	$234,995	$354,882

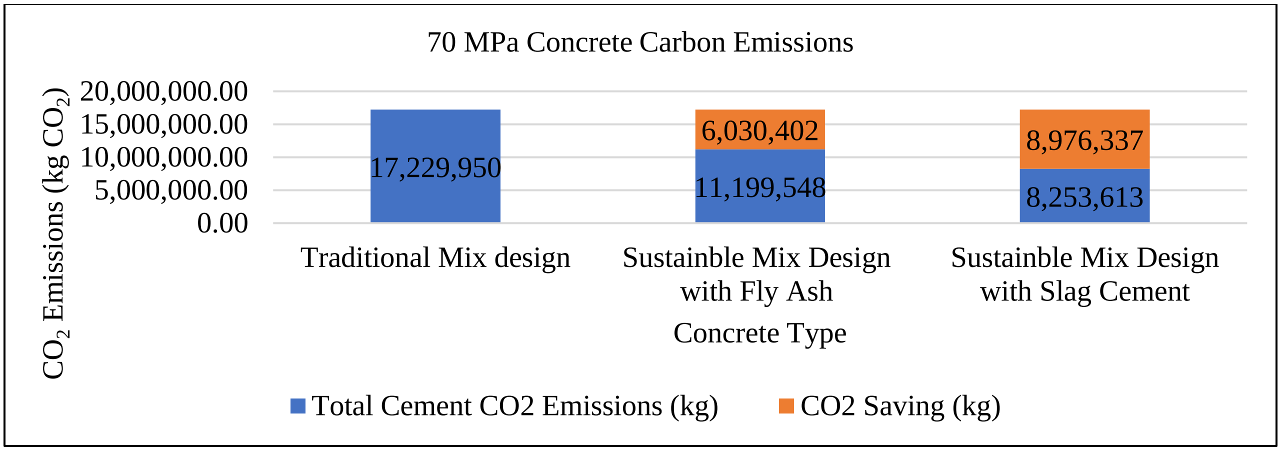


Figure 4-5: 70 MPa Concrete CO_2 Emissions

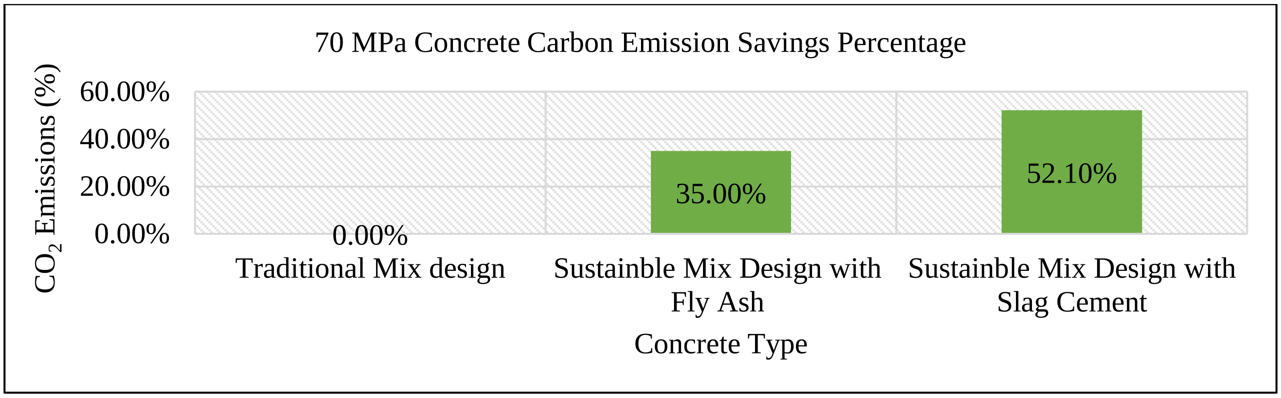


Figure 4-6: 70 MPa Concrete CO_2 Savings Percentage

Table 4-3: 70 MPa Concrete Mix Designs and Carbon Emission Savings

Concrete			
M70 Concrete	Traditional Mix design	Sustainable Mix Design with Fly Ash	Sustainable Mix Design with Slag Cement
Total Volume in M3	32,740	32,740	32,740
Cement in tons	21,012	13,658	10,065
Cement CO_2 Emission factor in Egypt 2020 kg CO_2 per ton cement.	820		
Total Cement CO_2 Emissions (kg CO_2)	17,229,950	11,199,548	8,253,613
CO_2 Saving (kg CO_2)	0	6,030,402	8,976,337
CO_2 Savings %	0.00%	35.00%	52.10%
Cost Saving US Dollars $	0	$261,116	$388,675

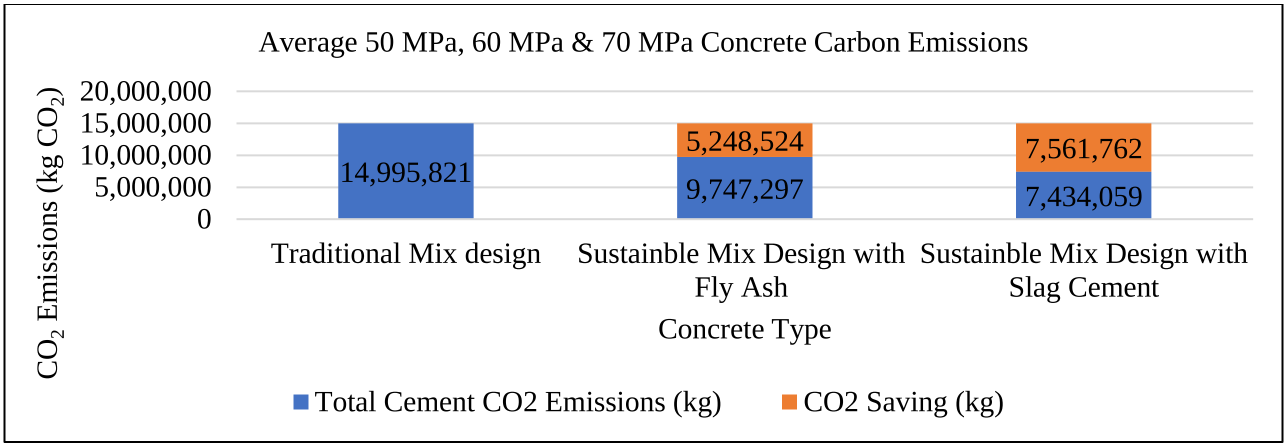


Figure 4-7: Average Concrete CO_2 Emissions

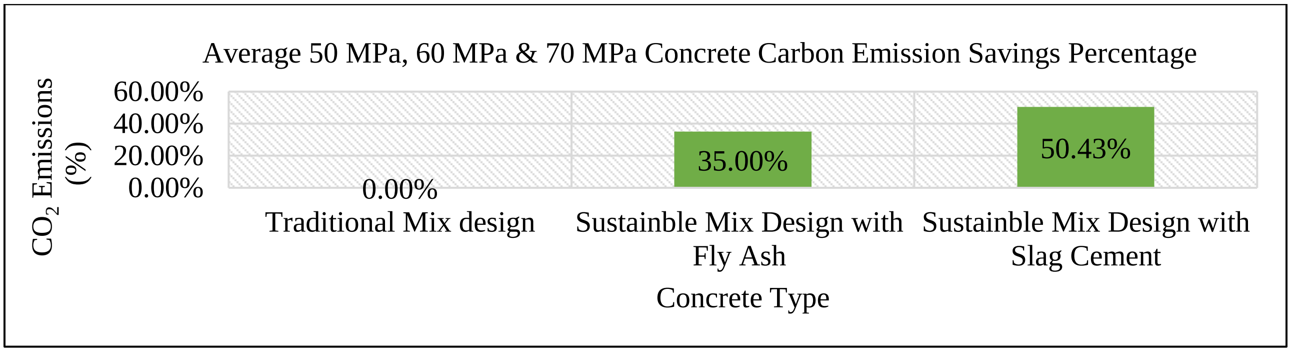


Figure 4-8: Average Concrete CO_2 Savings Percentage

Table 4-4: Average Concrete Mix Designs and Carbon Emission Savings

Concrete			
Average M50, M60 and M70 Concrete	Traditional Mix design	Sustainable Mix Design with Fly Ash	Sustainable Mix Design with Slag Cement
Cement in tons	18,288	11,887	9,066
Cement CO_2 Emission factor in Egypt 2020 kg CO_2 per ton cement.	820		
Total Cement CO_2 Emissions (kg CO_2)	14,995,821	9,747,297	7,434,059
CO_2 Saving (kg CO_2)	0	5,248,524	7,561,762
CO_2 Savings%	0.00%	35.00%	50.43%
Cost Saving US Dollars $	$0	$227,261	$327,424

The above concrete figures 4-1 to 4-8 and tables 4-1 to 4-4 summarize the evaluation of the model to three different concrete production configurations with three different strengths:

1. Traditional Concrete Mix, which is considered to be the base case for strengths of 50 MPa, 60 MPa, 70Mpa, and the realistic averaged concrete strength.

   A. For 50 MPa Traditional Concrete Mix was assumed to be used in all concrete elements like beams, columns, footing, and slabs of a High-Rise building, it results in an estimated CO_2 Emissions of 12,251,150 (kg CO_2). Equivalent to 1,452 Passenger cars driven for one year, 1,138 Houses' electricity use for one year, and 15,559 barrels of oil consumed for one year.

   B. For 60 MPa Traditional Concrete Mix was assumed to be used in all concrete elements like beams, columns, footing, and slabs of a High-Rise building, it results in an estimated CO_2 Emissions of 15,506,364 (kg CO_2). Equivalent to 1,838 Passenger cars driven for one year, 1,440 Houses' electricity use for one year, and 19,693 barrels of oil consumed for one year.

   C. For 70 MPa Traditional Concrete Mix was assumed to be used in all concrete elements like beams, columns, footing, and slabs of a High-Rise building, it results in an estimated CO_2 Emissions of 17,229,950 (kg CO_2). Equivalent to 2,042 Passenger cars driven for one year, 1,600 Houses' electricity use for one year, and 21,882 barrels of oil consumed for one year.

   D. Realistic averaged concrete strength is an average that is taken for the three strengths CO_2 emissions to reach a more realistic assumption for CO_2 emissions based on the usual usage of different concrete strengths within different concrete elements in a building. This resulted in an estimated CO_2 Emissions of 14,995,821 (kg CO_2). Equivalent to 1,777 Passenger cars driven for one year, 1,393 houses electricity use for one year, and 19,045 barrels of oil consumed for one year.

2. Sustainable Concrete Mix A is considered to use a lower cement quantity by 35% and add fly-ash for strengths of 50 MPa, 60 MPa, and 70Mpa.

   A. For 50 MPa, Sustainable Concrete Mix A was assumed to be used in all concrete elements like beams, columns, footing, and slabs of a High-Rise building; it results in an estimated CO_2 Emissions of 7,963,127 (kg CO_2), which is considered to be 35% lower CO_2 emission relative to the Primary case. Equivalent to 944 Passenger cars driven for one year, 740 Houses' electricity use for one year, and 10,113 barrels of oil consumed for one year. Therefore, CO_2 Saving is 4,288,023 (kg CO_2) and financial saving of $185,671 in comparison to the primary case.

   B. For 60 MPa, Sustainable Concrete Mix A was assumed to be used in all concrete elements like beams, columns, footing, and slabs of a High-Rise building; it results in an estimated CO_2 Emissions of 10,079,217 (kg CO_2), which is considered to be 35% lower CO_2 emission relative to the Primary case. Equivalent to 1,194 Passenger cars driven for one year, 936 Houses' electricity use for one year, and 12,801 barrels of oil consumed for one year. Therefore, CO_2 Saving is 5,427,147 (kg CO_2) and financial saving of $234,995 in comparison to the primary case.

   C. For 70 MPa, Sustainable Concrete Mix A was assumed to be used in all concrete elements like beams, columns, footing, and slabs of a High-Rise building; it results in an estimated CO_2 Emissions of 11,199,548 (kg CO_2), which is considered to be 35% lower CO_2 emission relative to the Primary case. Equivalent to 1,327 Passenger cars driven for one year, 1,040 Houses' electricity use for one year, and 14,223 barrels of oil consumed for one year. Therefore, CO_2 Saving is 6,030,402 (kg CO_2) and financial saving of $261,116 in comparison to the primary case.

   D. Realistic averaged concrete strength is an average that is taken for the three strengths CO_2 emissions to reach a more realistic assumption for CO_2 emissions based on the usual usage of different concrete strengths within different concrete elements in a building. This resulted in an estimated CO_2 Emissions of 9,747,297 (kg CO_2), which is considered to be

35% lower CO_2 emission relative to the Primary case. Equivalent to 1,155 Passenger cars driven for one year, 905 houses electricity use for one year, and 12,379 barrels of oil consumed for one year. Therefore, CO_2 Saving is 5,248,524 (kg CO_2) and financial saving of $227,261 in comparison to the primary case.

3. Sustainable Concrete Mix B is considered to use to lower cement quantity by 45% and add Slag Cement for strengths of 50 MPa, 60 MPa, and 70Mpa.

    A. For 50 MPa, Sustainable Concrete Mix B was assumed to be used in all concrete elements like beams, columns, footing, and slabs of a High-Rise building; it results in an estimated CO_2 Emissions of 6,738,092 (kg CO_2), which is considered to be 45% lower CO_2 emission relative to the Primary case, and 10% lower CO_2 emission relative to the Sustainable Concrete Mix A case. Equivalent to 799 Passenger cars driven for one year, 626 Houses' electricity use for one year, and 8,557 barrels of oil consumed for one year. Therefore, CO_2 Saving is 5,513,058 (kg CO_2) with a financial saving of $238,715 in comparison to the primary case, and a 28% increase in CO_2 savings and Financial savings compared to Sustainable Concrete Mix A.

    B. For 60 MPa, Sustainable Concrete Mix B was assumed to be used in all concrete elements like beams, columns, footing, and slabs of a High-Rise building; it results in an estimated CO_2 Emissions of 7,310,473 (kg CO_2), which is considered to be 52.86% lower CO_2 emission relative to the Primary case. Equivalent to 866 Passenger cars driven for one year, 679 Houses electricity use for one year, and 9,284 barrels of oil consumed for one year. Therefore, CO_2 Saving is 8,195,891 (kg CO_2) with a financial saving of $354,882 in comparison to the primary case, and a 51% increase in CO_2 savings and Financial savings compared to Sustainable Concrete Mix A.

    C. For 70 MPa, Sustainable Concrete Mix B was assumed to be used in all concrete elements like beams, columns, footing, and slabs of a High-Rise building; it results in an estimated CO_2 Emissions of 8,253,613 (kg CO_2), which is considered to be 52.1% lower CO_2 emission relative to the Primary case. Equivalent to 978 Passenger cars driven for one year, 767 Houses electricity use for one year, and 10,482 barrels of oil consumed for one year. Therefore, CO_2 Saving is 8,976,337 (kg CO_2) with a financial saving of $388,675 in comparison to the primary case, and a 48.9% increase in CO_2 savings and Financial savings compared to Sustainable Concrete Mix A.

D. Realistic averaged concrete strength is a median that is taken for the three strengths CO_2 emissions to reach a more realistic assumption for CO_2 emissions based on the usual usage of different concrete strengths within different concrete elements in a building. This resulted in an estimated CO_2 Emissions of 7,434,059 (kg CO_2), which is 50.43% lower CO_2 emission relative to the Primary case. Equivalent to 881 Passenger cars driven for one year, 690 houses electricity use for one year, and 9,441 barrels of oil consumed for one year. Therefore, CO_2 Saving is 7,561,762 (kg CO_2) with a financial saving of $327,424 in comparison to the primary case, and a 44% increase in CO_2 savings and Financial savings compared to Sustainable Concrete Mix A.

Thus, the findings show that the most sustainable is slag cement concrete mix with its various strengths. In addition to that, such sustainable concrete CO_2 emissions savings result in emphasizing the reduction of cement content in reaching more CO_2 and energy-efficient concrete mix designs, which deserve attention from lawmakers across the world to restructure laws and codes to regulate cement usage within a building.

4.2.2 STEEL MODEL OUTCOMES

The carbon emissions of steel are based on the manufacturing process. Therefore, the model analysis the two production routes, which are Traditional Blast Arc Furnace (BAF) and Electrical Arc Furnace (EAF). The model results are illustrated in figures 4-9 and 4-10, and table 4-5.

1. Traditional Blast Arc Furnace (BF)

   The Blast Arc furnace production route is the base case in which the total CO_2 emission per the amount of steel used in the High-rise building is 6,811,697 **(**kg CO_2). Equivalent to 799 Passenger cars driven for one year, 626 Houses' electricity use for one year, and 8,557 barrels of oil consumed for one year.

2. Electrical Arc Furnace (EAF)

   The Electrical Arc Furnace (EAF) production route is the sustainable version in which the total CO_2 emission is 1,443,517 (kg CO_2), equivalent to 319 Passenger cars driven for one year, 267 Houses electricity use for one year, and 3,401 barrels of oil consumed for one year. The CO_2 emission saving is 5,368,180 (kg CO_2), which is 78.81% saving relevant to the base case. In addition to that, the financial saving is $232,442.

Thus, the finding of this examination the result show that EAF produced steel is the most sustainable in terms of carbon emissions and reflects the vital role of value engineering in the sustainability of a building as it minimizes the steel usage within a high-rise building while not compromising the safety of the building's structure.

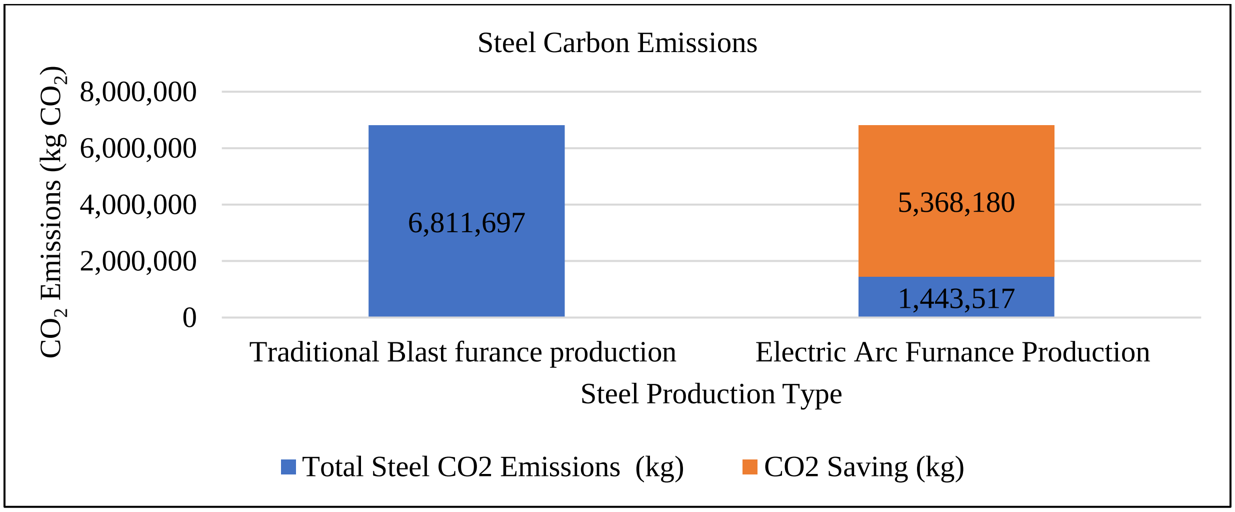


Figure 4-9: Steel CO_2 Emissions

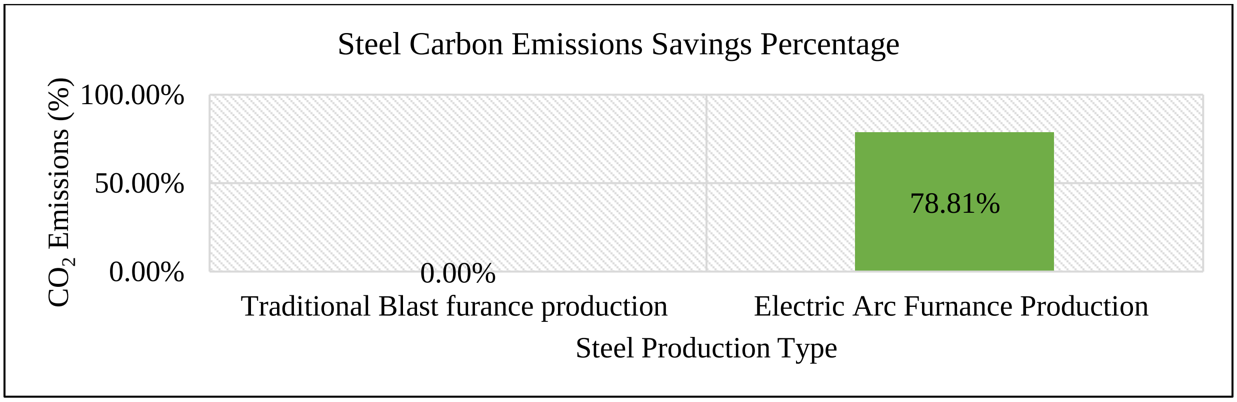


Figure 4-10: Steel CO_2 Savings percentage

Table 4-5: Steel CO_2 Emissions and Savings

Steel		
Steel CO_2 Emissions	Traditional Blast furnace production	Electric Arc Furnace Production
Total Weight of Steel tons	3,273	3,273
CO_2 Emissions Factor in the Production of Steel kg per ton	2081	441
Total Steel CO_2 Emissions (kg CO_2)	6,811,697	1,443,517
CO_2 Saving (kg CO_2)	0	5,368,180
CO_2 Savings %	0.00%	78.81%
Cost Saving US Dollars $	$0	$232,442

4.2.3 BRICKS MODEL OUTCOMES

Bricks carbon emissions were computed based on three types of bricks which are Traditional Clay bricks and sustainable versions of bricks like Concrete Bricks and Fly Ash Bricks. The model results are illustrated in figures 4-11 and 4-12, and table 4-6.

The clay bricks production produce about 755,200 (kg CO_2) equivalents to 163 Passenger cars driven for one year, 128 houses electricity use for one year, and 1,748 barrels of oil consumed for one year.

On the other hand, Concrete Bricks production produces about 435,200 (kg CO_2) equivalents to 94 Passenger cars driven for one year, 73.7 houses electricity use for one year, and 1,008 barrels of oil consumed for one year. In addition to that, concrete bricks production provides CO_2 emission saving and financial saving of 43.4%, equivalent to 320,000 (kg CO_2) and $13,856 in comparison to Traditional Clay bricks.

Besides that, Fly Ash Bricks production produces an even lower CO_2 emission of 140,800 (kg CO_2) equivalents to 30.4 Passenger cars driven for one year, 23.8 houses electricity use for one year, and 326 barrels of oil consumed for one year. In addition to that, Fly Ash production provides CO_2 emission saving and financial saving of 81.4%, equivalent to 614,400 (kg CO_2) and $26,603 in comparison to Traditional Clay bricks. Moreover, The CO_2 emission savings for Fly

Ash Bricks production relative to Concrete bricks production demonstrate a Financial saving and CO_2 Emission saving of 38.98% equivalent to 294,400 (kg CO_2) and $12,747.

Therefore, Fly Ash Bricks and concrete bricks production is considered to be more sustainable and with an increased CO_2 emission saving relative to Conventional Clay bricks due to the use of a chemical process in their products in exchange for the firing process used for traditional clay bricks. Moreover, Fly Ash bricks produce greater sustainability and CO_2 emission savings than concrete bricks as they do not include cement. Thus, fly ash is considered to be the most sustainable brick type. This finding encourages the use of fly ash bricks in the Egyptian and worldwide construction industry instead of conventional clay bricks. Such a motive can be achieved by providing tax reductions and privileges to producers.

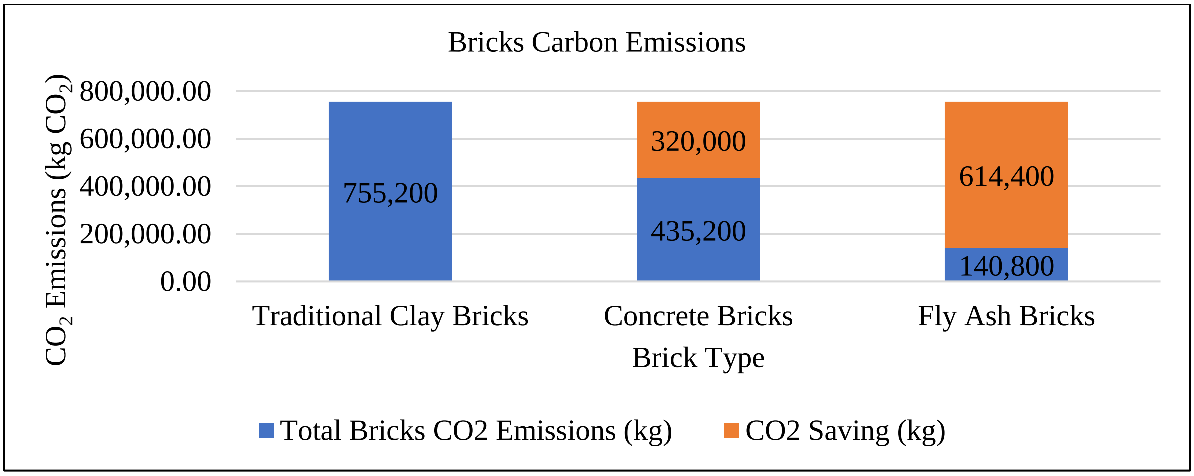


Figure 4-11: Bricks' CO_2 Emissions

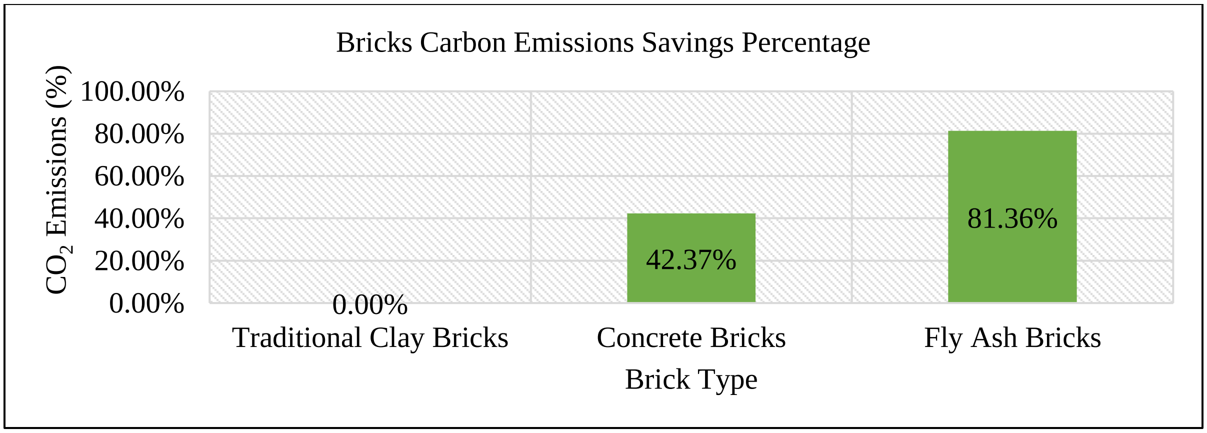


Figure 4-12: Bricks' CO_2 Savings percentage

Table 4-6: Bricks' CO_2 Emissions and Savings

Bricks			
Bricks CO_2 Emissions	Traditional Clay Bricks	Concrete Bricks	Fly Ash Bricks
Total Number of Bricks	1,280,000	1,280,000	1,280,000
CO_2 Emissions Factor per Brick	0.59	0.34	0.11
Total Bricks CO_2 Emissions	755,200	435,200	140,800
CO_2 Saving (kg CO_2)	0.00	320,000	614,400
CO_2 Savings%	0.0%	42.4%	81.4%
Cost Saving US Dollars $	$0.00	$13,856	$26,603

4.2.4 TRANSPORTATION MODEL OUTCOMES

Transportation emissions for construction materials were considered within the model. The average round trip distance traveled for all the construction materials trucks was considered to be 30km. The model results are illustrated in figure 4-13, and table 4-7.

For concrete transportation via concrete mixing trucks produces about 17,751 (kg CO_2). The transportation of concrete needs about 654 truckloads with a distance traveled of 19,620 km. on the other hand, Steel transportation via trucks produces about 5,719 (kg CO_2). The transportation of Steel need about 131 truckloads with a distance traveled of 3,928 km. In addition to that, brick transportation via trucks produces about 21,840 (kg CO_2). The transportation of bricks needs about 500 truckloads with a distance traveled of 15,000 km.

Therefore, this result show transportation is a vital producer of CO_2 emission within the construction of a building, thus considering a nearby batch plant and material suppliers is a sustainable movement that can affect the saving of CO_2 emissions.

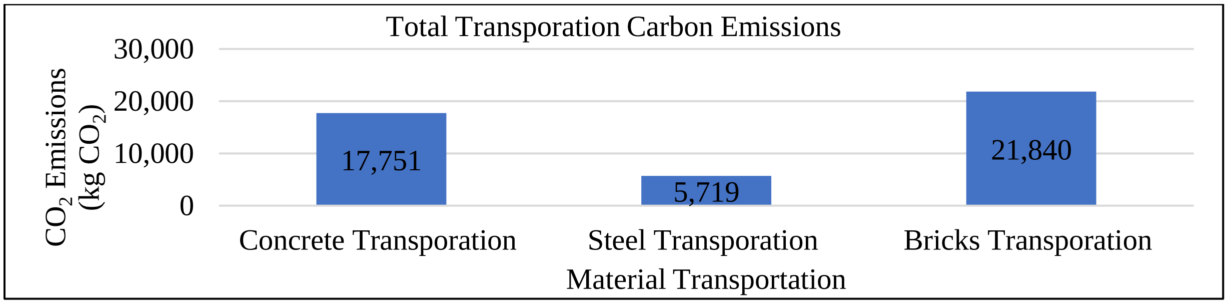


Figure 4-13: Total Transportation CO_2 Emissions

Table 4-7: Total Transportation CO_2 Emissions and Savings

Transportation			
Transportation	Concrete Transportation	Steel Transportation	Bricks Transportation
Average Round Trip Distance (km)	30	30	30
Truck Loads	654	131	500
Total Truck Distance Travelled	19,620	3,928	15,000
Diesel CO_2 Emissions Factor (kg/km)	0.90	1.46	1.46
Total Transportation CO_2 Emissions (kg CO_2)	17,751	5,719	21,840
Total Transportation CO_2 Emissions (kg CO_2)	45,310		

4.3 OPERATIONAL PHASE MODEL OUTCOMES

Through this section, carbon emissions for the operational phase were computed for high rise building's major energy consumers and indirect carbon producers during operation, which includes Light, Air Conditioners, Water Heaters, and window glazing. Quantitative comparative analysis for carbon emission was conducted for each element using conventional methods and sustainable methods. Correspondingly carbon saving was computed as the difference between both.

4.3.1 LIGHTING MODEL OUTCOMES

Light carbon emissions were computed based on the following light bulbs, which are conventional incandescent, sustainable compact fluorescent, and ultra-sustainable light-emitting diodes (LED). Each light gives the same luminance of 1,020 lumens but with different energy consumption in watt, thus different carbon emissions. The model results are illustrated in figures 4-14 and 4-15, and table 4-8.

The conventional incandescent light bulbs produce annually about 45,726 (kg CO_2) equivalents to 9.9 Passenger cars driven for one year and 106 barrels of oil consumed for one year.

On the other hand, compact fluorescent light bulbs produce annually about 10,479 (kg CO_2) equivalents to 2.3 Passenger cars driven for one year and 24.3 barrels of oil consumed for one year. In addition to that, compact fluorescent light bulbs provide CO_2 emission saving and financial saving of 77.1%, equivalent to 35,247 (kg CO_2) and $1,526 in comparison to conventional incandescent light bulbs.

Besides that, light-emitting diodes (LED) produce an even lower annual CO_2 emission of 6,669 (kg CO_2) equivalents to 1.4 Passenger cars driven for one year and 15.4 barrels of oil consumed for one year. In addition to that, light-emitting diodes (LED) provide CO_2 emission saving and financial saving of 85.4%, equivalent to 39,057 (kg CO_2) and $1,691 in comparison to conventional incandescent light bulbs. Moreover, the CO_2 emission savings for light-emitting diodes (LED) relative to compact fluorescent light bulbs demonstrate a Financial saving and CO_2 Emission saving of 8.3% equivalent to 3,810 (kg CO_2) and $164.

Therefore**,** light-emitting diodes (LED) are the most sustainable option to conventional incandescent light bulbs as they consume the least energy producing the least CO_2 Emission and giving the same lumens. Such findings encourage the use of LED Bulbs in Egypt and worldwide instead of conventional incandescent light bulbs. Such a motive can be achieved by providing tax reductions and privileges to LED light producers and lower costs on LED lights bulbs.

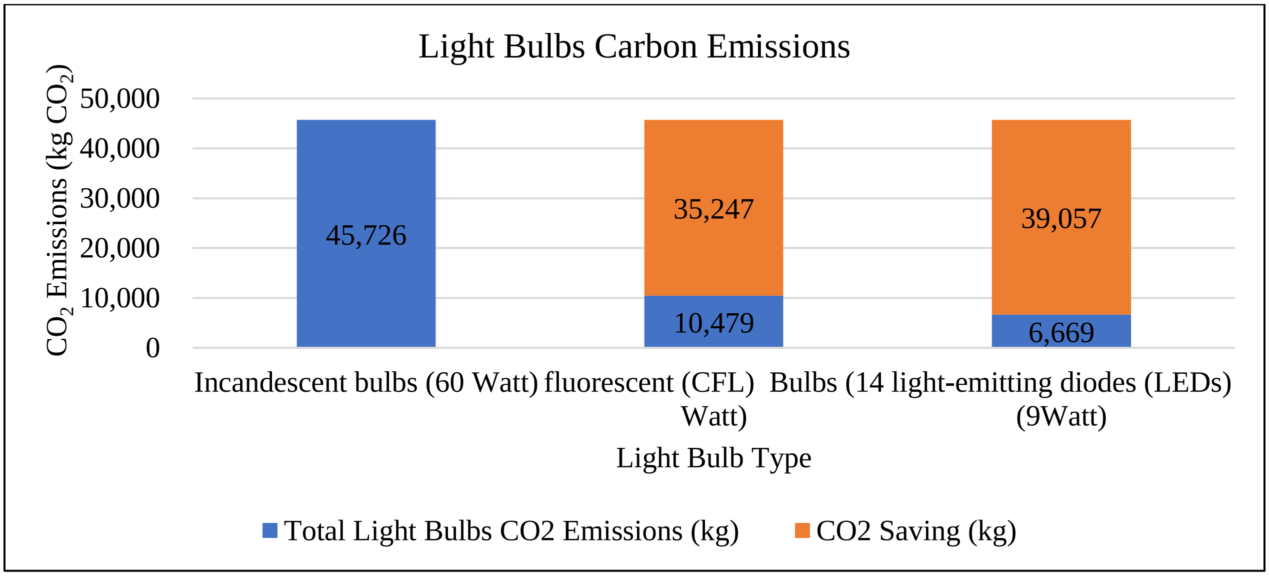


Figure 4-14: Light Bulbs CO_2 Emissions

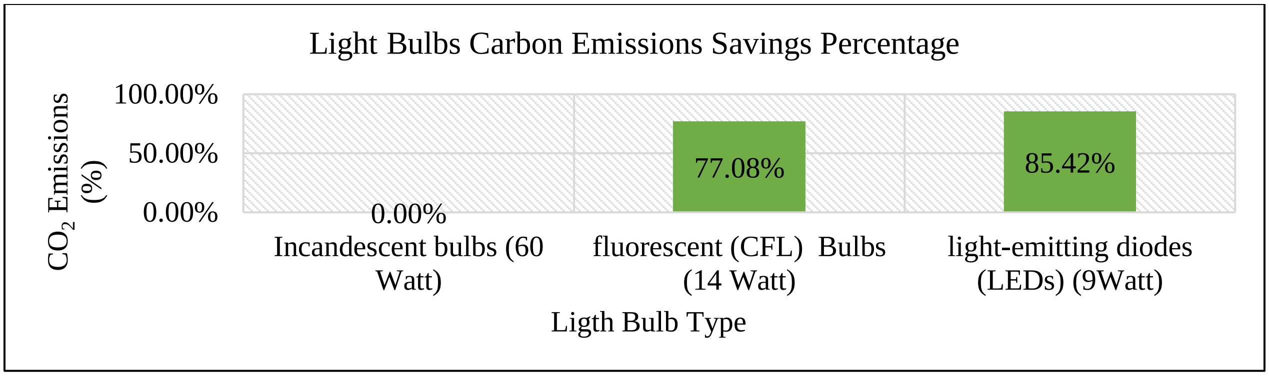


Figure 4-15: Light Bulbs CO_2 Emissions Savings Percentage

Table 4-8: Lights bulb's CO_2 Emissions and Savings

Lights			
Light Bulbs	Incandescent bulbs (60 Watt)	fluorescent (CFL) Bulbs (14 Watt)	light-emitting diodes (LEDs) (9 Watt)
Total Number of Light Bulbs	300	300	300
CO_2 Emissions Factor per year operation	152	34	22
Total Light Bulbs CO_2 Emissions	45,726	10,479	6,669
CO_2 Saving (kg CO_2)	0	35247	39057
CO_2 Savings%	0.0%	77.1%	85.4%
Cost Saving US Dollars $	$0.0	$1526	$1691

4.3.2 AIR CONDITIONING SYSTEMS MODEL OUTCOMES

Air conditioners carbon emissions were computed based on three types of air conditioner systems which are conventional Split AC system, Air Cooled Chilled Water AC system, and Water-Cooled Chilled water AC system. Each Air conditioner system gives the same cooling tons, but with different energy consumption in watt, thus different carbon emission. The model results are illustrated in figures 4-16 and 4-17, and table 4-9.

The conventional Split AC system produces annually about 25,618 (kg CO_2) equivalents to 5.5 Passenger cars driven for one year and 59.3 barrels of oil consumed for one year.

On the other hand, Air-cooled chilled water systems produce annually about 20,494 (kg CO_2) equivalents to 4.4 Passenger cars driven for one year and 47.4 barrels of oil consumed for one year. In addition to that, the air-cooled chilled water system provides CO_2 emission saving and financial saving of 20 % equivalent to 5,123 (kg CO_2) and $221 in comparison to conventional Split AC system.

Besides that, the Water-Cooled Chilled water system produces an even lower annual CO_2 emission of 11,955 (kg CO_2) equivalents to 2.6 Passenger cars driven for one year and 27.7 barrels of oil consumed for one year. In addition to that, the Water-Cooled Chilled water system provides CO_2 emission saving and financial saving of 53.3%, equivalent to 13,663 (kg CO_2) and $ 591 in comparison to conventional Split AC system. Moreover, the CO_2 emission savings for the Water-Cooled Chilled water system relative to Air-Cooled Chilled Water System demonstrate a Financial saving and CO_2 Emission saving of 33.3 % equivalent to 8,539 (kg CO_2) and $ 369.

Therefore**,** Water-Cooled Chilled water system is the most sustainable option to split AC systems in high-rise buildings as they consume the least energy producing the least CO_2 Emission and giving the same cooling tons. Such findings encourage the use of a Water-Cooled Chilled water system in Egypt instead of a conventional split AC system. Such motive can be achieved if the government motivate developers in adding Water-cooled chilled water systems in their buildings by providing tax reduction, vat reduction, reducing the cost of a water-cooled chilled water system and its availability in the market, and lowering water consumption bills on consumers encouraging them to demand this kind of system when looking for a new home.

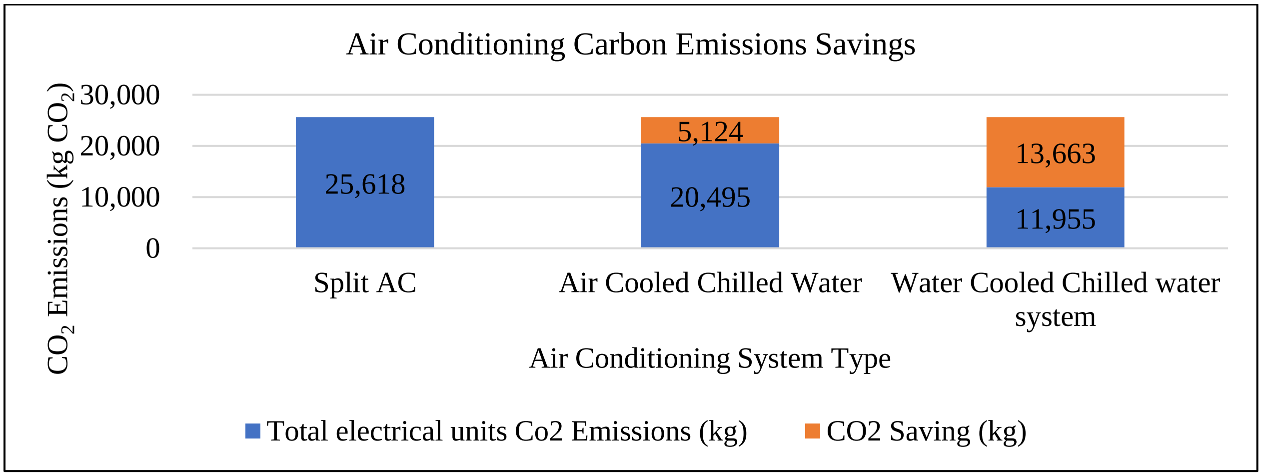


Figure 4-16: Air Conditioning Systems CO_2 Emissions

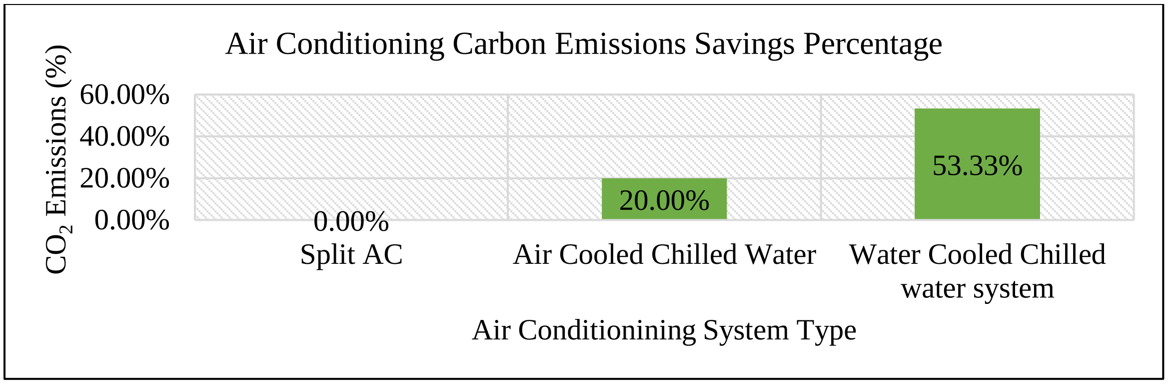


Figure 4-17: Air Conditioning Systems CO_2 Saving Percentage

Table 4-9: Air Conditioning Systems Emissions and Savings

Air Conditioner			
Air Conditioner	Split AC	Air Cooled Chilled Water	Water Cooled Chilled water system
Total Area of Building	142,560	142,560	142,560
Tons Required	3,410	3,410	3,410
Watt	5,115,789	4,092,631	2,387,368
Operation hours	12	12	12
CO_2 Emissions Factor in the consumption of electricity	0.000417	0.000417	0.000417
Total electrical units CO_2 Emissions	25618	20494	11955
CO_2 Saving (kg CO_2)	0.00	5123	13663
CO_2 Savings%	0.00%	20.0%	53.3%
Cost Saving US Dollars $	$0.00	$221	$591

4.3.3 WATER HEATERS MODEL OUTCOMES

Water Heaters carbon emissions were computed based on three types of water heating systems which are conventional Electrical tank water heaters, Electrical tankless water heaters, and Gas tankless water heaters. Each water heating system gives the same cooling tons but with different energy consumption in Watt or BTU, thus different carbon emissions. The model results are illustrated in figures 4-18 and 4-19, and table 4-10.

The conventional Electrical tank water heaters produce annually about 921 (kg CO_2) equivalents to 2.1 barrels of oil consumed for one year.

On the other hand, Electrical tankless water heaters produce annually about 787 (kg CO_2) equivalents to 1.8 barrels of oil consumed for one year. In addition to that, Electrical tankless water heaters provide CO_2 emission saving and financial saving of 14.6%, equivalent to 134 (kg CO_2) and $ 5.8 in comparison to conventional Electrical tank water heaters.

Besides that, Gas tankless water heaters produce an even lower annual CO_2 emission of 550 (kg CO_2) equivalents to 1.3 barrels of oil consumed for one year. In addition to that, Gas tankless water heaters provide CO_2 emission saving and financial saving of 40.29%, equivalent to 371 (kg CO_2) and $ 16 in comparison to conventional Electrical tank water heaters. Moreover, the CO_2 emission savings for Gas tankless water heaters relative to Electrical tankless water heaters demonstrate a Financial saving and CO_2 Emission saving of 25.7% equivalent to 237 (kg CO_2) and $ 10.3.

Therefore**,** Gas tankless water heaters are the most sustainable option for high-rise buildings as they consume the least energy producing the least CO_2 Emission. Such findings encourage the use of Gas tankless water heaters in Egypt instead of conventional electric tank water heaters.

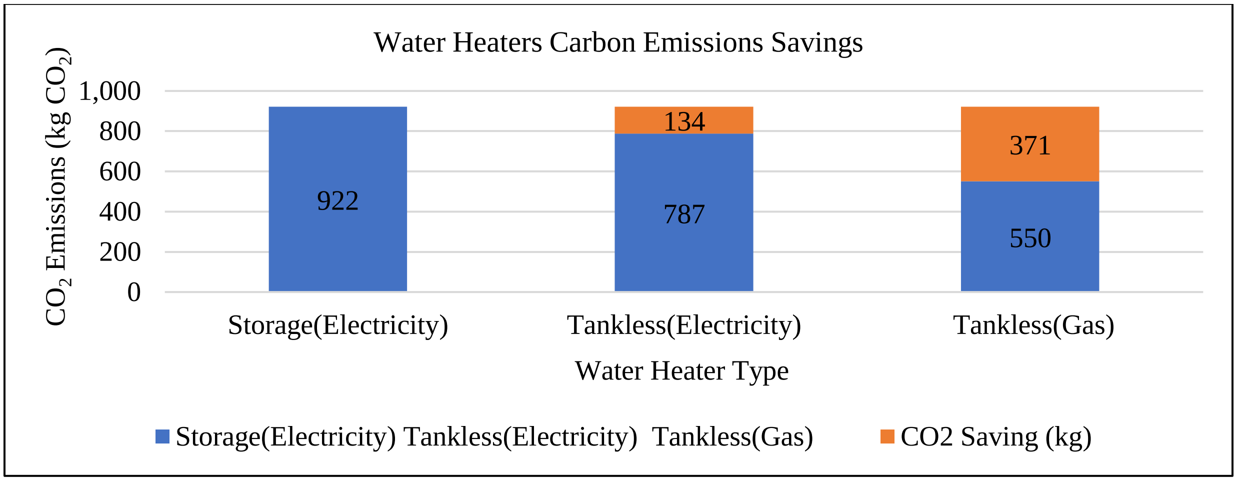


Figure 4-18: Water Heaters CO_2 Emissions

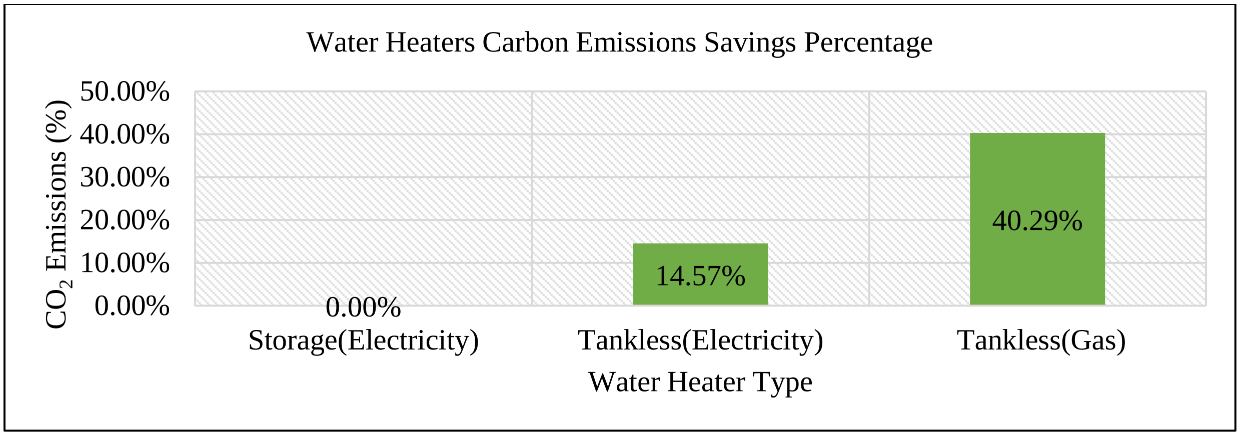


Figure 4-19: Water Heater CO_2 Emissions Savings Percentage

Table 4-10: Water Heater CO_2 Emissions and Savings

Water Heater			
Water Heaters	Storage (Electricity)	Tankless (Electricity)	Tankless (Gas)
Total Number of Units	50	50	50
Watt	2,500	4,500	0
Gas Consumption BTU	0	0	41,000
Watt /BTU to GJ/hr	0.009	0.016	0.043
Operation hours	8	4	4
CO_2 Emissions Factor in the consumption of electricity	256	243	63.6
Total electrical units CO_2 Emissions	921	787	550
CO_2 Saving (kg CO_2)	0.0	134	371
CO_2 Savings%	0.0%	14.6%	40.3%
Cost Saving US Dollars $	$0.00	$5.8	$16.1

4.3.4 DOUBLE GLAZED WINDOWS MODEL OUTCOMES

In this section, carbon emission of window double glazing will be examined relative to conventional single glazing reducing heat transfer, reducing air conditioner's cooling tons, thus reducing Carbon emissions. The model results are illustrated in figures 4-20 and 4-21, and table 4-11. Based on the Model data and literature review, a conclusion has been reached that double glazing reduces cooling tons by 5%. Based on the findings, it illustrates that Low-e double-glazed windows decrease CO_2 emission by an average of 1,040 kg CO_2 with conventional Split AC system, Air Cooled Chilled Water AC system and Water-Cooled Chilled water AC system and increasing each air conditioning system saving by 5%. Thus, double glazed windows can be implemented by emphasizing contractors and developers to use double glazed windows in their existing buildings and futuristic building projects.

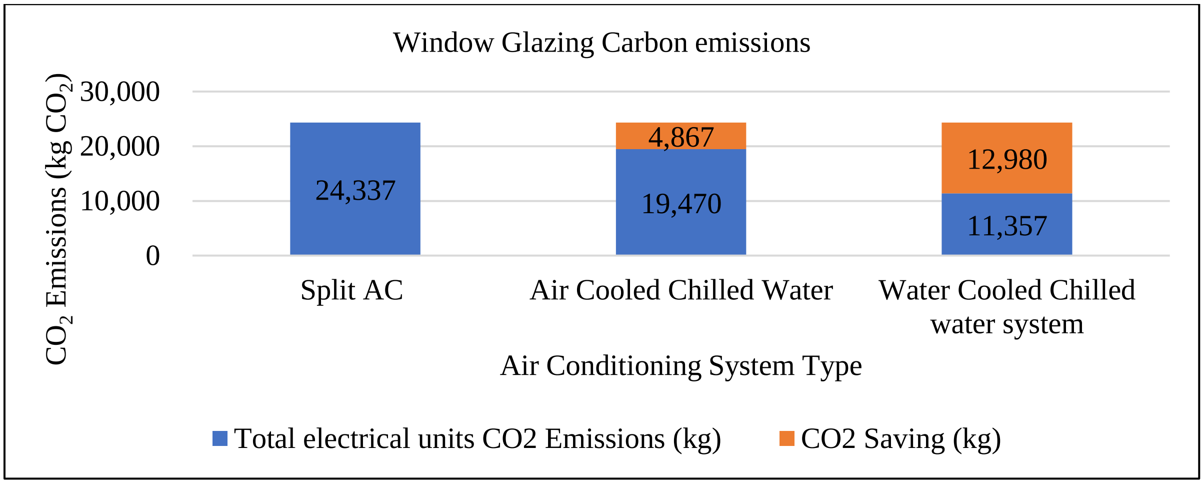


Figure 4-20: Window Glazing CO_2 Emissions

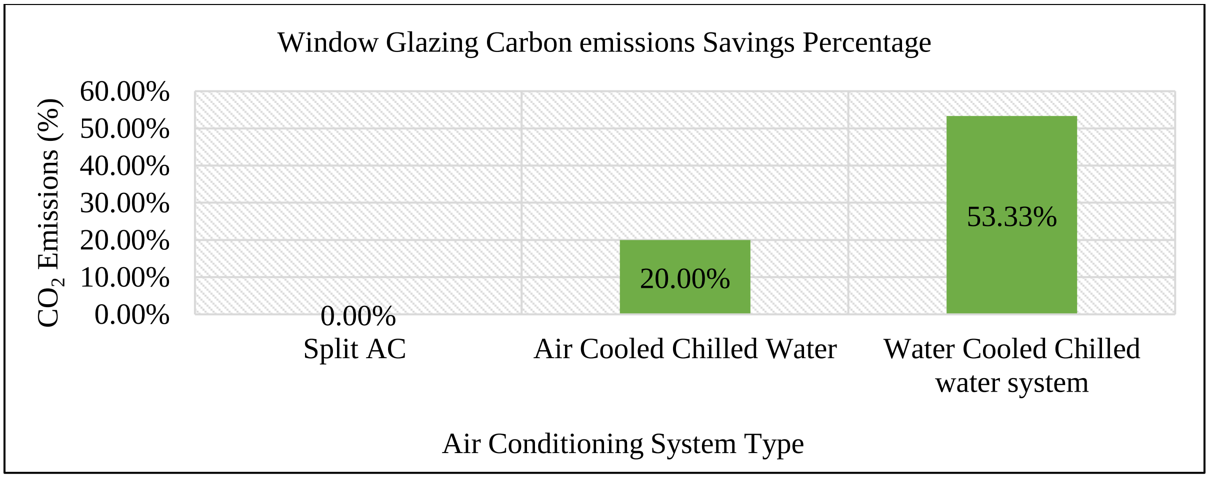


Figure 4-21: Window Glazing CO_2 emissions saving percentage.

Table 4-11: Window Glazing CO_2 Emissions and Savings

Window Glazing			
Window Glazing	Split AC	Air Cooled Chilled Water	Water Cooled Chilled water system
Total CO_2 Emission	25,618	20,495	11,955
Saving	0.05	0.05	0.05
Total electrical units CO_2 Emissions	24,337	19,470	11,357
CO_2 Saving (kg CO_2)	0	4,867	12,980
CO_2 Savings%	0.00%	20.00%	53.33%
Cost Saving US Dollars $	$0	$211	$562

4.4 SUMMARY OF MODEL ANALYSIS FOR CONSTRUCTION and OPERATION CARBON EMISSIONS:

In conclusion, Table 4-12 and Figure 4-22 summarizes and illustrates the analysis on the amount of carbon emission savings that can be accomplished for both construction and operational phases of high-rise buildings in two different combinations.

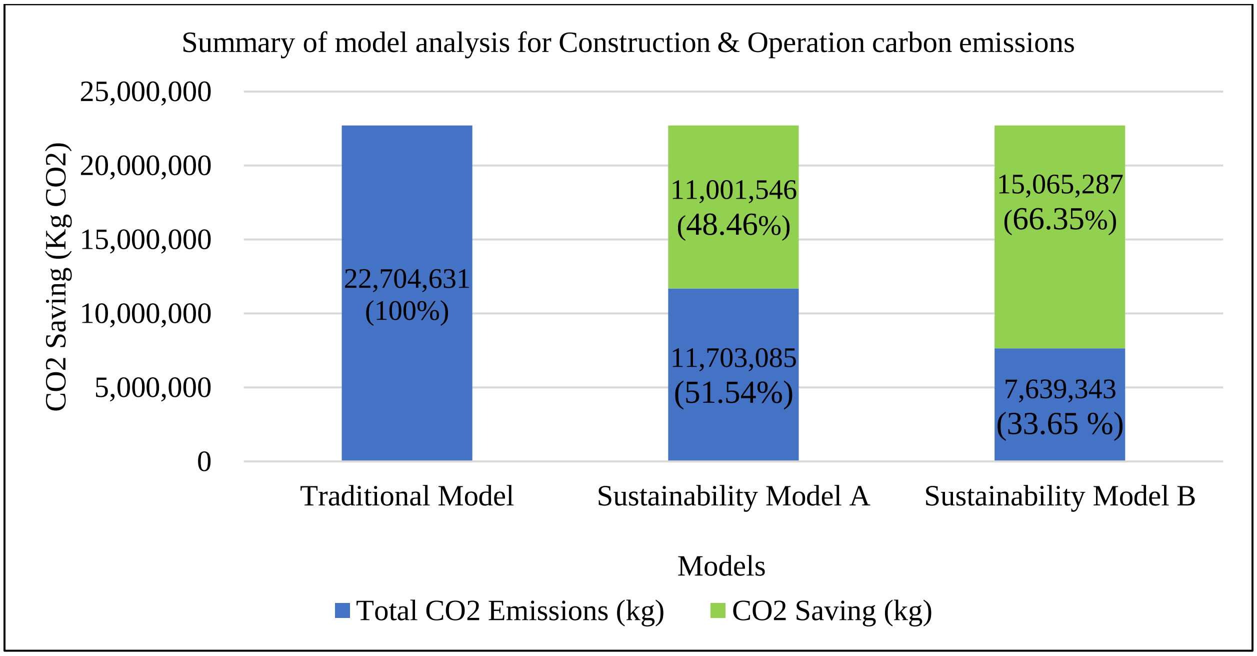


Figure 4-22: Summary of model analysis for Construction and Operation carbon emissions

Table 4-12: Summary of model analysis for Construction and Operation carbon emissions

Models	Traditional Model	Sustainability Model A	Sustainability Model B
Total CO_2 Emissions (kg CO_2)	22,704,631	11,703,085	7,639,343
CO_2 Saving (kg CO_2)	0	11,001,546	15,065,287
CO_2 Savings%	0.00%	48.46%	66.35%
Cost Saving US $ Annually	$0	$476,367	$652,327

The analysis illustrates the maximum amount of carbon emission saving can be reached if all conditions are met like in Sustainability model A which involve the use of Fly ash Concrete mix, Concrete bricks, EAF produced Steel, Compact Fluorescent light bulbs, tankless electric water heaters, Air Cooled Chilled water, and double-glazed windows. Sustainability Mix A reveals a CO_2 emission production of 11,703,085 (kg CO_2), CO_2 emission saving of 11,001,546 (kg CO_2), which represents a 48.46% saving relative to the conventional model. The carbon emission saving for Sustainability model A is equivalent to removing 2,393 petrol-fueled passenger vehicles from the streets annually, 1,998 home electricity usage for one year, and planting 181,913 trees.

In addition to that, the analysis reveals the optimum amount of carbon emission saving can be reached if all the conditions are met like in Sustainability model B, which include Slag Concrete mix, Fly Ash Bricks, EAF produced steel, Light Emitting Diode (LED) Bulbs, tankless water heater, water-cooled air conditioners, and double-glazed windows. Sustainability Model B demonstrates a CO_2 emission production of 7,639,343 (kg CO_2), CO_2 emission saving of 15,065,287 (kg CO_2), which represents a 66.35% saving relative to the conventional model. The carbon emission saving for Sustainability model A is equivalent to removing 3,276 petrol-fueled passenger vehicles from the streets annually, 1,695,205 home electricity usage for one year, and planting 249,108 trees.

4.4.1 CONSTRUCTION VERSUS USE-PHASE CARBON SAVINGS

Based on the analysis of the optimum sustainable case, which is Sustainability Model B, the construction phase and operational phase carbon saving differs throughout the building life span as summarized in figure 4-23 and figure 4-24, which illustrate the percentage of contribution of each phase. In the initial lifetime of high-rise buildings construction emphasize a more powerful influence on carbon emission saving in comparison to operational phase which is approximately $ 590,000 to $0 in the first year as the building is still under construction. Such ratio changes as the building construction finished and the operation of the building starts.

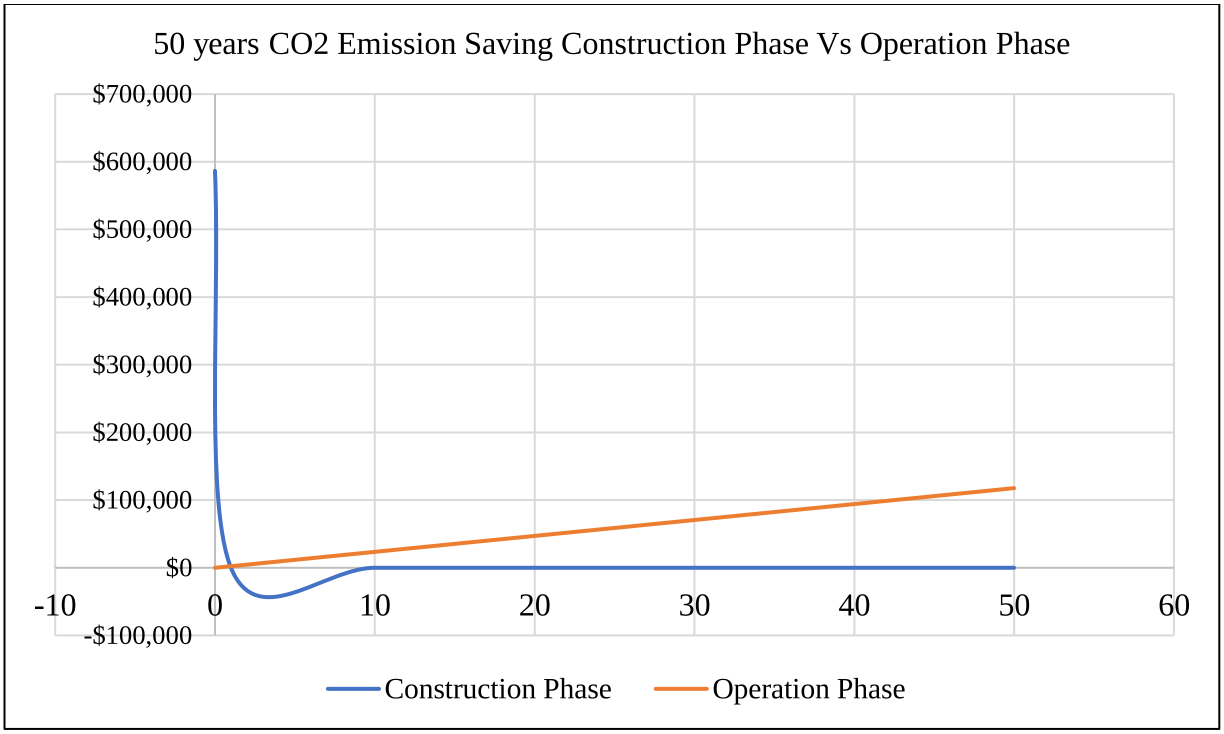


Figure 4-23: CO_2 Emission Saving Construction Phase Vs Operation Phase for 50 years

In the model, the maintenance of the building through its lifetime was not considered; thus, no change will affect the construction phase afterward as this step is completed. On the other hand, operational savings continue to accumulate and increase annually as the building's carbon efficiency increases from main operational elements (Light, Water Heaters, Air conditioners, and double-glazed windows).

By the end of a high-rise building 50-year lifespan, operational saving can achieve about 16.71% of total carbon emission savings. Thus, the choice of construction materials can be more influential in carbon saving and environmental sustainability than operational elements.

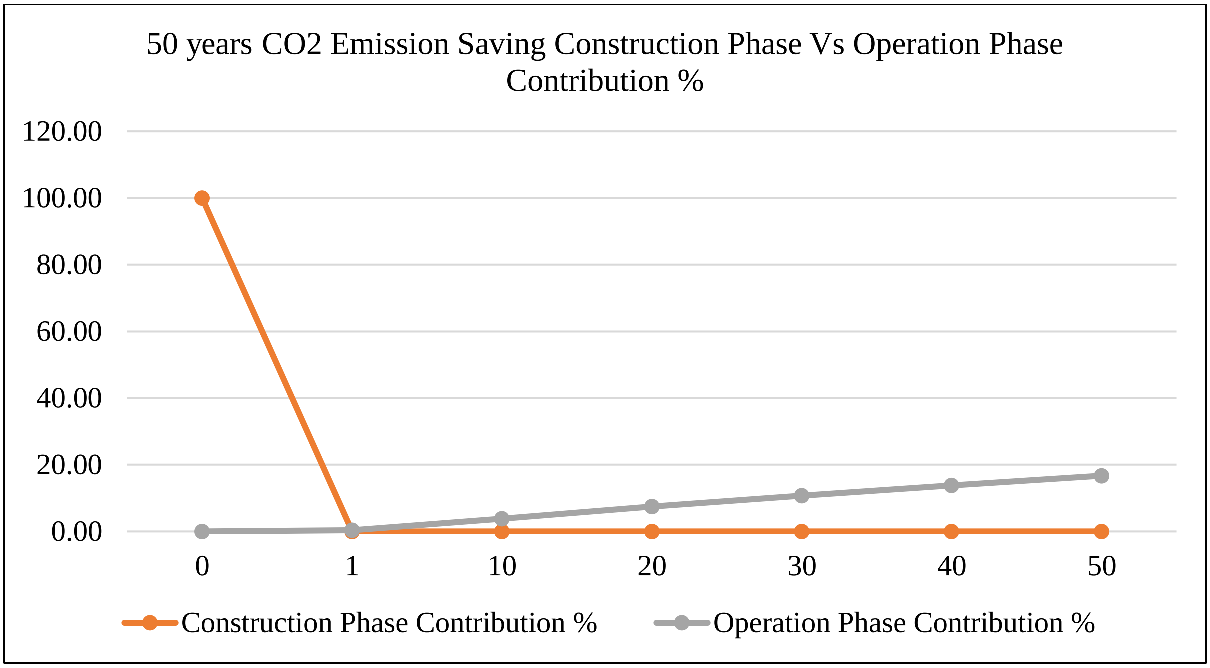


Figure 4-24: CO_2 Emission Saving Construction Phase Vs Operation Phase Contribution percentage for 50 Years.

4.4.2 FINANCIAL ANALYSIS OF CARBON EMISSIONS SAVINGS

The estimated cost of carbon in 2020, as earlier stated in the model assumptions section, is about $ 43.3 per ton of CO_2. Placing into consideration the benchmark to the carbon emissions savings of the model as summarized in table 4-13 and illustrated in figure 4-25, which both summarizes the carbon emission financial savings that can be reached in the construction and operational phase high rise buildings in two different combinations. This analysis focuses on using the construction and operational phase yearly assuming constructing and operating one building each year.

The analysis reveals the maximum amount of financial carbon emission saving can be reached if all conditions are met like in Sustainability model A which demonstrate carbon financial saving of $ 476,367 annually and according to a 50-year duration it would save about $ 24,389,988.

Besides that, Sustainability model B reveals financial carbon emission of $ 652,327 annually, and according to a 50-year duration, it would save about $ 33,399,139. Decreased CO_2 emission not only help the environment, but it can also have a main role in relieving the subsequent cost to society and to a nation.

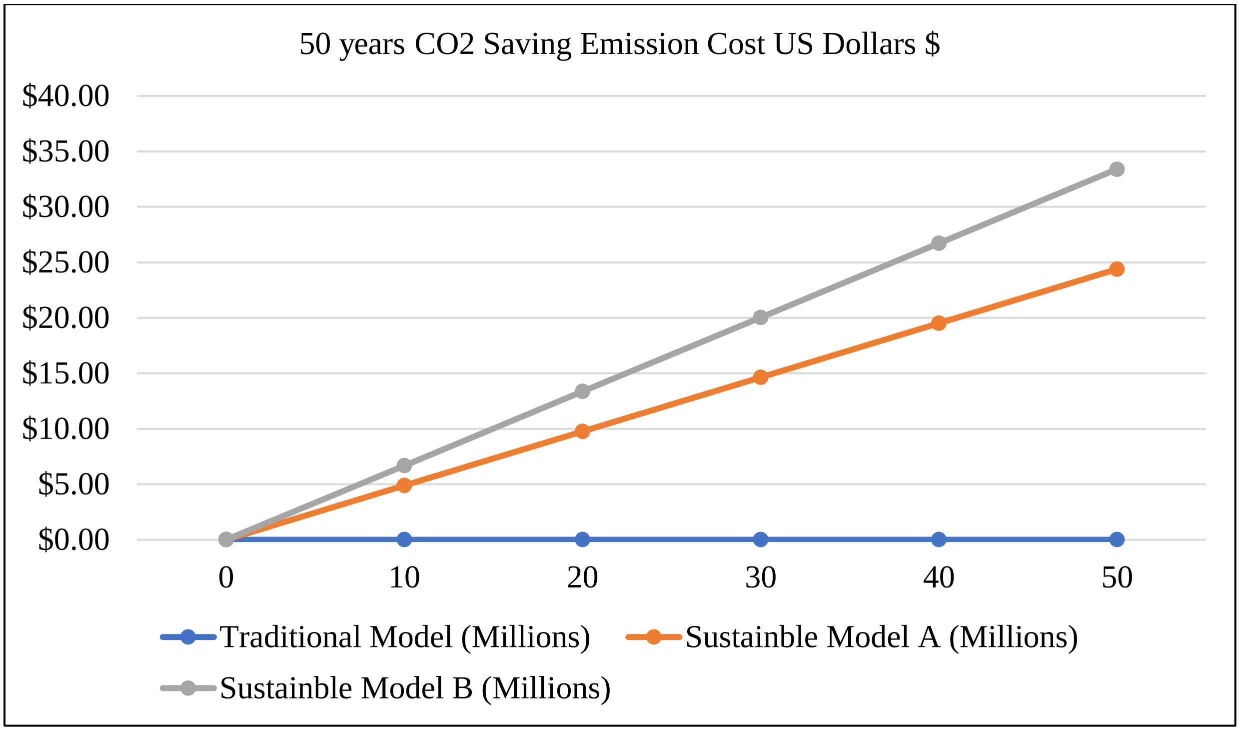


Figure 4-25: CO_2 Emissions Cost Saving in US Dollars $ for 50 years.

Table 4-13 and figure 4-25 summarize the effects of high-rise buildings construction phase and operation phase over 50 years, which is considered to be a breakeven point for the return of investment for the operational lifespan of a building in Egypt. Nevertheless, Financial savings from reducing CO_2 emission not only reduce the cost on society though, but it can also have a main role in energy saving, thus leading to an energy cost saving to the society and to nations.

However, Energy-saving was not analyzed in the study, yet it can be examined by future research by reference to the marginal cost of electricity and Levelized cost of electricity in Egypt, which both target the analysis of the average cost per kWh of electricity in power plant building and operation, and comparative economic analysis on the cost of electricity generation between various energy generations methods in Egypt.

Table 4-13: CO_2 Emission Cost Saving in US Dollars $ for 50 Years.

50 years Carbon Emissions Cost Savings in US Dollars $			
Years	Traditional Model (Millions)	Sustainable Model A (Millions)	Sustainable Model B (Millions)
0	$0.00	$0.00	$0.00
10	$0.00	$4.88	$6.68
20	$0.00	$9.76	$13.36
30	$0.00	$14.63	$20.04
40	$0.00	$19.51	$26.72
50	$0.00	$24.39	$33.40

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

With Egypt's vision of 2030 announced in 2015, focusing on sustainable development with a major emphasis on carbon emission reduction in its newly built cities and high-rise buildings, methods and implements are crucial in accomplishing the vision’s goals. There are several tools and models associated with aiding the reduction of carbon emissions; however, through the investigation, there has been a significant gap in high-rise buildings carbon emission calculations in Egypt, which were considered an advantage in developing a computational model and examination on. This study develops and evaluates a comprehensive carbon model framework for high-rise building construction and operation activities and testing the model’s validation through analytic analysis. The model can be used as a guide for high rise building carbon emission calculation and should be expanded to areas that were not covered in the study, which include embodied carbon lifecycle analysis, all-electric appliances and equipment, renewable energy sources, outdoor façade lighting, and construction materials like ceramic tiles, marble tiles paints, dry walls, and vinyl flooring. The summarized findings of this work include:

1. High-rise building major carbon producer’s construction materials are concrete, steel and bricks.
    a. Concrete is considered to be the main carbon emitters among all construction materials and operational elements within a high-rise building. The usage of Mineral admixtures in concrete lowers the amount of cement in a concrete mix design, which can improve carbon emission saving by up to 52% with the usage of slag and 35% with the usage of fly ash.

    b. Electric Arc Furnace (EAF) produced steel consumes less energy in manufacturing compared to Conventional Blast furnace (BOF) produced steel, thus reducing the carbon emissions by 78.8% in comparison to conventional (BOF).

   c. Bricks have the maximum ability to save carbon emissions among all construction materials. Non-fire produced bricks like Concrete and fly ash bricks have lower CO_2 emissions compared to conventional fire produced clay bricks. Fly ash bricks are more sustainable with lower CO_2 emissions compared to concrete and conventional clay bricks as they can save up to 81% in comparison to conventional clay bricks. On the other hand, concrete bricks can save up to 42% in comparison to clay bricks.

2. High-rise building major operational carbon emitters are lights, water heaters, air conditioners, and double-glazed windows.

   a. Lighting is one of the major operational carbon producers within a high-rise building. LED bulbs are extremely sustainable with high carbon saving light bulbs compared to Compact Fluorescent bulbs and conventional bulbs as they save about 85% of carbon emission. At the same time, compact fluorescent bulbs save about 77% of carbon emissions.

   b. Tankless gas water heaters and tankless electrical water heaters are sustainable and produce superior carbon saving compared to conventional electric tank water heaters. Tankless gas water heaters are extremely sustainable and carbon efficient as they save about 40% in carbon emission compared to conventional tank electric water heaters. In contrast, Tankless electrical water heaters save about 14% in comparison to conventional ones.

   c. Air Conditioners are the largest carbon emission producers among operational elements within a high-rise building, and they also contribute with the most carbon savings. The water-cooled and air-cooled air conditioning systems are the most sustainable and carbon savers to be implemented in a high-rise building in comparison to conventional split unit air conditioning systems. Water-cooled air conditioning systems contribute to a 51% carbon saving, while air-cooled air conditioning systems provide a 16% carbon saving.

    d. Double glazed windows have a tremendous effect on additional carbon savings as they contribute with a 5% carbon saving on each air conditioning system savings by lowering AC Cooling tons, thus lowering the energy consumption of the air conditioning system.

3. Adopting Sustainable Model B practices in high-rise buildings can reduce carbon emissions by 66.35%, in comparison to conventional practices. On the other hand, implementing sustainable model A methods can reduce carbon emissions to 48.46%.

4. High-rise building lifetime carbon savings are significantly attributed to the operational phase of the building more than the construction phase.

5. High-rise buildings Cost and Carbon saving for a 50-year projection using Sustainable model B is \$33,399,139 and 15,065,287 (kgCO_2) and using Sustainable model A is \$24,389,988 and 11,001,546 (kgCO_2).

6. The Model produced in this study can be considered as an adequate tool for the assessment of Carbon dioxide emissions, yet this model needs to be further enhanced to be adapted to a wide range of applications.

5.2 RECOMMENDATIONS

5.2.1 RECOMMENDATIONS FOR FUTURE WORK

Various recommendations can be attained throughout the investigation which can be tackled in upcoming potential studies. They can be summarized into the following:

- Performing the same model analysis for carbon emissions for high-rise buildings with expanding the scope of work and incorporating more construction materials with the understanding and analysis of the material to carbon emission savings for a high-rise building. Such materials could include Gypsum dry walls, wood, paint, marble, ceramics, doors, insulations, and mirrors.

- Exploring carbon emission saving of the usage of recycled coarse and fine aggregates on High rise buildings.
- Conducting research on the effects of carbon emission saving on more brick types and comparing to conventional clay bricks. Such bricks would include cement dust blended bricks, Autoclaved aerated concrete (AAC) and earth compressed bricks.
- Developing a high-rise building model analyzing carbon emission and energy-saving while including more operational elements like water pumps, heating elements, building envelope elements, heat transfer building studies, automated light sensors, automated thermostat sensors, automated energy and carbon emission management interface, and electrical appliances and office appliances for residential buildings or mixed-use buildings.
- Evolving the high-rise building carbon emission model to serve specific building types like residential, commercial building types or mixed-use building types, or even other types of construction sectors like roads and pavements and considering all the detailed elements of each building type or construction sector with the needed numerical assumptions and analysis.
- Expanding the high-rise building carbon emission model to focus not only on carbon emission but on energy while adding renewable energy methods, which can have a huge impact on carbon saving and energy savings. Such high-rise building renewable energy methods include.
- Performing a similar study with the focus on Methane as it is considered to be even more dangerous than Carbon dioxide, as it has four times the global warming effect on the atmosphere.
- Validating and developing the Model further in comparison to several High-rise buildings case studies in a theoretical and experimental manner to reach a higher level of result accuracy.
- Developing the high-rise building carbon emission model to focus not only on isolated and strip footings, but to include more types of footings e.g., Raft footings, Pile Footings, and Combined Footings.

5.2.2 RECOMMENDATIONS FOR THE CONSTRUCTION INDUSTRY

Hence, bearing in mind the study conclusions, several recommendations for the construction industry have been developed. The recommendation is considered to have long-term applications due to the impact of governmental and governing bodies' issuance of rules and regulations, and challenges consuming more time and cost to be implemented within the industry but comes with a benefit of long-term savings. The recommendations are as follow:

1. Improving the concrete mix design through every project restricting excessive cement use, while cement is the major producer of carbon emissions within concrete. Such aspects can be implemented by governmental enforcing of regulation to influence the local concrete producers to limit their use of cement and use energy and carbon-efficient mix designs.

2. Converting all light fixtures in existing buildings to Light-emitting diode (LED) and enforcing developers in using (LED) lighting in newly constructed buildings and developments, as the use of LED gives an enormous potential in carbon and energy savings. This can be quickly implemented by the government restricting the importing and production of incandescent light fixtures and bulbs by increasing their producer taxes and consumption taxes. On the other hand, LED light fixtures and bulb producers and importers will be given governmental privileges like tax exemptions, and LED consumers are given governmental supports on LED bulbs and Fixtures like installment plans, strict 5-year operational warranties.

3. Using tankless gas water heaters or solar water heaters in all existing and new buildings by the enforcement of governmental regulations on building permits emphasizing the use of built-in tankless gas water heaters within building to serve the building as a whole or separately for each unit.

4. Emphasizing existing building owners and new building developers to use double glazed windows by increasing public awareness media campaigns of electrical bill saving they can reach by implementing double glazed windows. In addition to that, imposing developers on using double glazed windows in their new projects by making it part of the government building permits and completion certificates regulations.

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APPENDIX I:
(CONCRETE MIX DESIGNS)

CONCRETE MIX DESIGN (GRADE M60)
DESIGN STIPULATION:

- Specific gravity of cement = 3.15
- Specific gravity of fine aggregate (F.A) = 2.6
- Specific gravity of Coarse aggregate (C.A) = 2.64
- Dry Rodded Bulk Density of fine aggregate = 1726 kg/m^3
- Dry Rodded Bulk Density of coarse aggregate = 1638 kg/m^3

Step-1: Select Concrete Target Strength, Slump, and Maximum Nominal Aggregate size:

- Target strength = 1.10 * 8700 + 700 = 10270 PSI = 71 MPa *From ACI 211.4R-08 Equation 3-3*
- Slump = 25 mm to 50 mm before using Superplasticizer *from ACI 211.4R-08 Table 6.1*
- Max size of aggregate used = 12.5 mm *From ACI 211.4R-08 Table 6.2*

Step-2: Calculation for weight of Coarse Aggregate:

- Fractional volume of oven dry Rodded C.A for 12.5 mm size aggregate = 0.68m^3 *From ACI 211.4R-08 Table 6.3*
- Weight of C.A = 0.68*1638 = 1113.84 kg/m^3

Step-3: Calculation for Quantity of Water and Entrapped Air:

- Assuming Slump as 25 to 50mm and for C.A size 12.5 mm the Mixing water = 175 kg/m3 *From ACI 211.4R-08 Table 6.3*
- Entrapped air Content: 2.0
- Void content of FA for this mixing water = 35%
  Void content of FA (V)
  V = {1-(Dry Rodded unit weight / specific gravity of FA*1000)}*100 *From ACI 211.4R-08 Equation 6-2*
  = [1-(1726/2.6*1000)]*100
  = 34.62%
- Adjustment in mixing water = (V-35) * 4.55 *From ACI 211.4R-08 Equation 6-3*
  = (34.62 – 35)*4.55
  = -1.725 kg/m3
  Total water required = 175 + (-1.725) = 173.28 kg/m3

Step-4: Calculation for weight of cement:

- Take W / C ratio = 0.30 *By interpolation from ACI 211.4R-08 Table 6.5*
- Weight of cement = 173.28 / 0.30 = 577.58 kg/m^3

Step-5: Calculation for weight of Fine Aggregate:

- Cement = 577.58 / 3.15*1000= 0.1834 m^3
  Water = 173.28 / 1*1000= 0.1733 m^3
  CA = 1113.84 / 2.64*1000= 0.4219 m^3
  Entrapped Air = 2 / 100= 0.020 m^3
  Total = 0.7986 m^3
- Volume of Fine Aggregate= 1-0. 7986= 0.2014
- Weight of Fine Aggregate= 0.2393*2.6*1000= 523.64 kg/m^3

Step-6: Super plasticizer:

For 0.8% = (0.8 / 100)* 173.28 = 1.386 kg/ m^3

Step-7: Correction for water:

Weight of water (For 0.8%) =176.28 – 1.386 = 174.89 kg/m^3

Requirement of materials per Cubic meter

Cement = 577.58 kg/m^3
Fine Aggregate = 523.64 kg/m^3
Coarse Aggregate = 1113.84 kg/m^3
Water = 174.89 kg/ m^3
Superplasticizer = 1.386 kg/ m^3

The final ratio

Cement: 1
Fine aggregate (kg/m^3): 0.91
Coarse aggregate (kg/m^3): 1.93
Water (l/m^3): 0.30
Superplasticizer = 0.0024

CONCRETE MIX DESIGN (GRADE M60) with Fly ASH C 35% Replacement

DESIGN STIPULATION:

- Specific gravity of cement = 3.15
- Specific gravity of fine aggregate (F.A) = 2.6
- Specific gravity of Coarse aggregate (C.A) = 2.64
- Specific gravity of Fly Ash Type C = 2.64
- Dry Rodded Bulk Density of fine aggregate = 1726 kg/m^3
- Dry Rodded Bulk Density of coarse aggregate = 1638 kg/m^3

Step-1: Select Concrete Target Strength, Slump, and Maximum Nominal Aggregate size:

- Target strength = 1.10 * 8700 + 700 = 10270 PSI = 71 MPa *From ACI 211.4R-08 Equation 3-3*
- Slump = 25 mm to 50 mm before using Superplasticizer *from ACI 211.4R-08 Table 6.1*
- Max size of aggregate used = 12.5 mm *From ACI 211.4R-08 Table 6.2*

Step-2: **Calculation for weight of Coarse Aggregate:**

- Fractional volume of oven dry Rodded C.A for 12.5 mm size aggregate = 0.68m^3 *From ACI 211.4R-08 Table 6.3*
- Weight of C.A = 0.68*1638 = 1113.84 kg/m^3

Step-3: **Calculation for Quantity of Water and Entrapped Air:**

- Assuming Slump as 25 to 50mm and for C.A size 12.5 mm the Mixing water = 175 kg/m3 *From ACI 211.4R-08 Table 6.3*
- Entrapped air Content: 2.0
- Void content of FA for this mixing water = 35%
  Void content of FA (V)
  V = {1-(Dry Rodded unit weight / specific gravity of FA*1000)}*100 *From ACI 211.4R-08 Equation 6-2*
  = [1-(1726/2.6*1000)]*100
  = 34.62%
- Adjustment in mixing water = (V-35) * 4.55 *From ACI 211.4R-08 Equation 6-3*
  = (34.62 – 35)*4.55
  = -1.725 kg/m3
  Total water required = 175 + (-1.725) = 173.28 kg/m3

Step-4: **Calculation for weight of cement:**

- Take W / C ratio = 0.30 *By interpolation from ACI 211.4R-08 Table 6.5*
- Weight of cement = 173.28 / 0.30 = 577.58 kg/m^3

Step-5: **Fly Ash :**
For 35% Fly ASH Class C = 0.35*577.58 = 202.15 kg/m^3 *from ACI 211.4R-08*
Concrete = 577.58 – 202.15 = 375.43 *from ACI 211.4R-08*

Step-6: **Calculation for weight of Fine Aggregate:**

- Cement = 375.43 / 3.15*1000= 0.1192 m^3
  Fly Ash = 202.15 / 2.64*1000 = 0.0766 m^3
  Water = 173.28 / 1*1000= 0.1733 m^3
  CA = 1113.84 / 2.64*1000= 0.4219 m^3
  Entrapped Air = 2 / 100= 0.020 m^3
  Total = 0.811 m^3
- Volume of Fine Aggregate= 1-0.811 = 0.189 m^3
- Weight of Fine Aggregate= 0.189*2.6*1000= 491.4 kg/m^3

Step-7: Super plasticizer:
For 0.8% = (0.8 / 100)* 173.28 = 1.386 kg/ m^3

Step-8: **Correction for water:**
Weight of water (For 0.8%) =176.28 – 1.386 = 174.89 kg/m^3

Requirement of materials per Cubic meter

Cement = 375.43 kg/m^3
Fly Ash = 202.15 kg/m^3
Fine Aggregate = 491.4 kg/m^3
Coarse Aggregate = 1113.84 kg/m^3
Water = 174.89 kg/ m^3
Superplasticizer = 1.386 kg/ m^3

The final ratio

Cement: 1
Fly Ash = 0.538
Fine aggregate = 1.31
Coarse aggregate = 2.97
Water = 0.47
Superplasticizer = 0.00367

CONCRETE MIX DESIGN (GRADE M60) with Slag Cement 45% Replacement

DESIGN STIPULATION:

- Specific gravity of cement = 3.15
- Specific gravity of fine aggregate (F.A) = 2.6
- Specific gravity of Coarse aggregate (C.A) = 2.64
- Specific gravity of Slag Cement = 2.85
- Dry Rodded Bulk Density of fine aggregate = 1726 kg/m^3
- Dry Rodded Bulk Density of coarse aggregate = 1638 kg/m^3
- *Grade 100 Slag Cement will be used from ACI 211.4R-08 figure 8.3 and 8.4*

Step-1: Select Concrete Target Strength, Slump, and Maximum Nominal Aggregate size:

- Target strength = 1.10 * 8700 + 700 = 10270 PSI = 71 MPa *From ACI 211.4R-08 Equation 3-3*
- Slump = 25 mm to 50 mm before using Superplasticizer *from ACI 211.4R-08 Table 6.1*
- Max size of aggregate used = 12.5 mm *From ACI 211.4R-08 Table 6.2*

Step-2: **Calculation the portion of the required average compressive strength Fcr, regulated to Portland cement:**

- *The maximum relative compressive strength of the plain Portland cement mixture should be 114% based on figure 8.4*
- *Pc(psi)= fcr*100/(sci%) = 10270*100/114 = 9009 PSI = 62 MPa from ACI 211.4R-08 figure 8.3 and 8.4*

Calculation for weight of Coarse Aggregate:

- Fractional volume of oven dry Rodded C.A for 12.5 mm size aggregate = 0.68m^3 *From ACI 211.4R-08 Table 6.3*
- Weight of C.A = 0.68*1638 = 1113.84 kg/m^3

Step-3: **Calculation for Quantity of Water and Entrapped Air:**

- Assuming Slump as 25 to 50mm and for C.A size 12.5 mm the Mixing water = 175 kg/m3 *From ACI 211.4R-08 Table 6.3*
- Entrapped air Content: 2.0
- Void content of FA for this mixing water = 35%
  Void content of FA (V)
  V = {1-(Dry Rodded unit weight / specific gravity of FA*1000)}*100 *From ACI 211.4R-08 Equation 6-2*
  = [1-(1726/2.6*1000)]*100
  = 34.62%
- Adjustment in mixing water = (V-35) * 4.55 *From ACI 211.4R-08 Equation 6-3*
  = (34.62 – 35)*4.55
  = -1.725 kg/m3
  Total water required = 175 + (-1.725) = 173.28 kg/m3

Step-4: **Calculation for weight of cement:**

- Take W / C ratio = 0.35 *By interpolation from ACI 211.4R-08 Table 6.5*
- Weight of cement = 173.28 / 0.35 = 495.09 kg/m^3

Step-5: **Amount of Slag Cement :**

For 45% Slag Cement = 0.45*495.09 = 222.79 kg/m^3 *from ACI 211.4R-08 the maximum strength point based on figure 8.4 lies in 45% Slag Cement Content*

Portland Cement = 495.09 – 222.79 = 272.3 kg/m^3 *from ACI 211.4R-08*

Step-6: **Calculation for weight of Fine Aggregate:**

- Portland Cement = 272.3 / 3.15*1000= 0.0864 m^3
  Slag Cement = 222.79 / 2.85*1000 = 0.0782 m^3
  Water = 173.28 / 1*1000= 0.1733 m^3
  CA = 1113.84 / 2.64*1000= 0.4219 m^3
  Entrapped Air = 2 / 100= 0.020 m^3
  Total = 0.7798 m^3
- Volume of Fine Aggregate= 1-0.7798 = 0.2202 m^3
- Weight of Fine Aggregate= 0.2202 *2.6*1000= 572.52 kg/m^3

Step-7: Super plasticizer:

For 0.8% = (0.8 / 100)* 173.28 = 1.386 kg/ m^3

Step-8: **Correction for water:**

Weight of water (For 0.8%) =176.28 – 1.386 = 174.89 kg/m^3

Requirement of materials per Cubic meter

Portland Cement = 272.3 kg/m^3
Slag Cement = 222.79 kg/m^3
Fine Aggregate = 572.52 kg/m^3
Coarse Aggregate = 1113.84 kg/m^3
Water = 174.89 kg/ m^3
Superplasticizer = 1.386 kg/ m^3

The final ratio

- Portland Cement: 1
  Slag Cement = 0.818
  Fine aggregate = 2.102
  Coarse aggregate = 4.09
  Water = 0.642
  Superplasticizer = 0.00509

CONCRETE MIX DESIGN (GRADE M70)
DESIGN STIPULATION:

- Specific gravity of cement = 3.15
- Specific gravity of fine aggregate (F.A) = 2.6
- Specific gravity of Coarse aggregate (C.A) = 2.64
- Dry Rodded Bulk Density of fine aggregate = 1726 kg/m^3
- Dry Rodded Bulk Density of coarse aggregate = 1638 kg/m^3

Step-1: Select Concrete Target Strength, Slump, and Maximum Nominal Aggregate size:

- Target strength = 1.10 * 10153 + 700 = 11868 PSI = 82 MPa *From ACI 211.4R-08 Equation 3-3*
- Slump = 25 mm to 50 mm before using Superplasticizer *from ACI 211.4R-08 Table 6.1*
- Max size of aggregate used = 12.5 mm *From ACI 211.4R-08 Table 6.2*

Step-2: Calculation for weight of Coarse Aggregate:

- Fractional volume of oven dry Rodded C.A for 25 mm size aggregate = 0.75m^3 *From ACI 211.4R-08 Table 6.3*
- Weight of C.A = 0.68*1638 = 1113.84 kg/m^3

Step-3: Calculation for Quantity of Water and Entrapped Air:

- Assuming Slump as 25 to 50mm and for C.A size 12.5 mm the Mixing water = 175 kg/m3 *From ACI 211.4R-08 Table 6.3*
- Entrapped air Content: 2.0
- Void content of FA for this mixing water = 35%
  Void content of FA (V)
  V = {1-(Dry Rodded unit weight / specific gravity of FA*1000)}*100 *From ACI 211.4R-*

08 Equation 6-2
= [1-(1726/2.6*1000)]*100
= 34.62%

- Adjustment in mixing water = (V-35) * 4.55 *From ACI 211.4R-08 Equation 6-3*
  = (34.62 – 35)*4.55
  = -1.725 kg/m3
  Total water required = 175 + (-1.725) = 173.28 kg/m3

Step-4: **Calculation for weight of cement:**

- Take W / C ratio = 0.27 *By interpolation from ACI 211.4R-08 Table 6.5*
- Weight of cement = 173.28 / 0.27 = 641.78 kg/m^3

Step-5: **Calculation for weight of Fine Aggregate:**

- Cement = 641.78 / 3.15*1000= 0.2037 m^3
  Water = 173.28 / 1*1000= 0.1733 m^3
  CA = 1113.84 / 2.64*1000= 0.4219 m^3
  Entrapped Air = 2 / 100= 0.020 m^3
  Total = 0.8189 m^3
- Volume of Fine Aggregate= 1-0.8189= 0.1811
- Weight of Fine Aggregate= 0.1811*2.6*1000= 470.86 kg/m^3

Step-6: Super plasticizer:
For 0.8% = (0.8 / 100)* 173.28 = 1.386 kg/ m^3

Step-7: **Correction for water:**
Weight of water (For 0.8%) =176.28 – 1.386 = 174.89 kg/m^3

Requirement of materials per Cubic meter

Cement = 641.78 kg/m^3
Fine Aggregate = 470.86 kg/m^3
Coarse Aggregate = 1113.84 kg/m^3
Water = 174.89 kg/ m^3
Superplasticizer = 1.386 kg/ m^3

The final ratio

Cement: 1
Fine aggregate (kg/m^3): 0.73
Coarse aggregate (kg/m^3): 1.74
Water (l/m^3): 0.27
Superplasticizer = 0.00216

CONCRETE MIX DESIGN (GRADE M70) with Fly ASH C 35% Replacement
DESIGN STIPULATION:

- Specific gravity of cement = 3.15
- Specific gravity of fine aggregate (F.A) = 2.6
- Specific gravity of Coarse aggregate (C.A) = 2.64
- Specific gravity of Fly Ash Type C = 2.64
- Dry Rodded Bulk Density of fine aggregate = 1726 kg/m^3
- Dry Rodded Bulk Density of coarse aggregate = 1638 kg/m^3

Step-1: Select Concrete Target Strength, Slump, and Maximum Nominal Aggregate size:

- Target strength = 1.10 * 10153 + 700 = 11868 PSI = 82 MPa *From ACI 211.4R-08 Equation 3-3*
- Slump = 25 mm to 50 mm before using Superplasticizer *from ACI 211.4R-08 Table 6.1*
- Max size of aggregate used = 12.5 mm *From ACI 211.4R-08 Table 6.2*

Step-2: Calculation for weight of Coarse Aggregate:

- Fractional volume of oven dry Rodded C.A for 12.5 mm size aggregate = 0.68m^3 *From ACI 211.4R-08 Table 6.3*
- Weight of C.A = 0.68*1638 = 1113.84 kg/m^3

Step-3: Calculation for Quantity of Water and Entrapped Air:

- Assuming Slump as 25 to 50mm and for C.A size 12.5 mm the Mixing water = 175 kg/m3 *From ACI 211.4R-08 Table 6.3*
- Entrapped air Content: 2.0
- Void content of FA for this mixing water = 35%
  Void content of FA (V)
  V = {1-(Dry Rodded unit weight / specific gravity of FA*1000)}*100 *From ACI 211.4R-08 Equation 6-2*
  = [1-(1726/2.6*1000)]*100
  = 34.62%
- Adjustment in mixing water = (V-35) * 4.55 *From ACI 211.4R-08 Equation 6-3*
  = (34.62 – 35)*4.55
  = -1.725 kg/m3
  Total water required = 175 + (-1.725) = 173.28 kg/m3

Step-4: Calculation for weight of cement:

- Take W / C ratio = 0.27 *By interpolation from ACI 211.4R-08 Table 6.5*
- Weight of cement = 173.28 / 0.27 = 641.78 kg/m^3

Step-5: Fly Ash :

For 35% Fly ASH Class C = 0.35*641.78 = 224.62 kg/m^3 *from ACI 211.4R-08*
Concrete = 641.78 – 224.62 = 417.16 *from ACI 211.4R-08*

Step-6: **Calculation for weight of Fine Aggregate:**

- Cement = 417.16 / 3.15*1000= 0.1324 m^3
  Fly Ash = 224.62 / 2.64*1000 = 0.0850 m^3
  Water = 173.28 / 1*1000= 0.1733 m^3
  CA = 1113.84 / 2.64*1000= 0.4219 m^3
  Entrapped Air = 2 / 100= 0.020 m^3
  Total = 0.833 m^3
- Volume of Fine Aggregate= 1-0.833 = 0.167 m^3
- Weight of Fine Aggregate= 0.167*2.6*1000= 434.2 kg/m^3

Step-7: Super plasticizer:
For 0.8% = (0.8 / 100)* 173.28 = 1.386 kg/ m^3

Step-8: **Correction for water:**
Weight of water (For 0.8%) =176.28 – 1.386 = 174.89 kg/m^3

Requirement of materials per Cubic meter

Cement = 417.16 kg/m^3
Fly Ash = 224.62 kg/m^3
Fine Aggregate = 434.2 kg/m^3
Coarse Aggregate = 1113.84 kg/m^3
Water = 173.28 kg/ m^3
Superplasticizer = 1.386 kg/ m^3

The final ratio

Cement: 1
Fly Ash = 0.54
Fine aggregate = 1.04
Coarse aggregate = 2.67
Water = 0.42
Superplasticizer = 0.00332

CONCRETE MIX DESIGN (GRADE M70) with Slag Cement 45% Replacement
DESIGN STIPULATION:

- Specific gravity of cement = 3.15
- Specific gravity of fine aggregate (F.A) = 2.
- Specific gravity of Coarse aggregate (C.A) = 2.64
- Specific gravity of Slag Cement = 2.85
- Dry Rodded Bulk Density of fine aggregate = 1726 kg/m^3
- Dry Rodded Bulk Density of coarse aggregate = 1638 kg/m^3
- *Grade 100 Slag Cement will be used from ACI 211.4R-08 figure 8.3 and 8.4*

Step-1: Select Concrete Target Strength, Slump, and Maximum Nominal Aggregate size:

- Target strength = 1.10 * 10153 + 700 = 11868 PSI = 82 MPa *From ACI 211.4R-08 Equation 3-3*
- Slump = 25 mm to 50 mm before using Superplasticizer *from ACI 211.4R-08 Table 6.1*
- Max size of aggregate used = 12.5 mm *From ACI 211.4R-08 Table 6.2*

Step-2: Calculation the portion of the required average compressive strength Fcr, regulated to Portland cement:

- *The maximum relative compressive strength of the plain Portland cement mixture should be 114% based on figure 8.4*
- *Pc(psi)= fcr*100/(sci%)* = 11868**100/114 = 10410.53 PSI = 71.78* MPa *from ACI 211.4R-08 figure 8.3 and 8.4*

Calculation for weight of Coarse Aggregate:

- Fractional volume of oven dry Rodded C.A for 12.5 mm size aggregate = 0.68m^3 *From ACI 211.4R-08 Table 6.3*
- Weight of C.A = 0.68*1638 = 1113.84 kg/m^3

Step-3: Calculation for Quantity of Water and Entrapped Air:

- Assuming Slump as 25 to 50mm and for C.A size 12.5 mm the Mixing water = 175 kg/m3 *From ACI 211.4R-08 Table 6.3*
- Entrapped air Content: 2.0
- Void content of FA for this mixing water = 35%
  Void content of FA (V)
  V = {1-(Dry Rodded unit weight / specific gravity of FA*1000)}*100 *From ACI 211.4R-08 Equation 6-2*
  = [1-(1726/2.6*1000)]*100
  = 34.62%
- Adjustment in mixing water = (V-35) * 4.55 *From ACI 211.4R-08 Equation 6-3*
  = (34.62 – 35)*4.55
  = -1.725 kg/m3
  Total water required = 175 + (-1.725) = 173.28 kg/m3

Step-4: Calculation for weight of cement:

- Take W / C ratio = 0.31 *By interpolation from ACI 211.4R-08 Table 6.5*
- Weight of cement = 173.28 / 0.31 = 558.97 kg/m^3

Step-5: Amount of Slag Cement :

For 45% Slag Cement = 0.45*558.97 = 251.54 kg/m^3 *from ACI 211.4R-08 the maximum strength point based on figure 8.4 lies in 45% Slag Cement Content*

Portland Cement = 558.97 – 251.54 =307.43 kg/m^3 *from ACI 211.4R-08*

Step-6: Calculation for weight of Fine Aggregate:

- Portland Cement = 307.43 / 3.15*1000= 0.0976 m^3
  Slag Cement = 251.54 / 2.85*1000 = 0.0883 m^3
  Water = 173.28 / 1*1000= 0.1733 m^3
  CA = 1113.84 / 2.64*1000= 0.4219 m^3
  Entrapped Air = 2 / 100= 0.020 m^3
  Total = 0.8011 m^3
- Volume of Fine Aggregate= 1-0.8011 = 0.1989 m^3
- Weight of Fine Aggregate= 0.1989 *2.6*1000= 517.14 kg/m^3

Step-7: Super plasticizer:

For 0.8% = (0.8 / 100)* 173.28 = 1.386 kg/ m^3

Step-8: Correction for water:

Weight of water (For 0.8%) =176.28 – 1.386 = 174.89 kg/m^3

Requirement of materials per Cubic meter

Portland Cement = 307.43 kg/m^3
Slag Cement = 251.54 kg/m^3
Fine Aggregate = 517.14 kg/m^3
Coarse Aggregate = 1113.84 kg/m^3
Water = 174.89 kg/ m^3
Superplasticizer = 1.386 kg/ m^3

The final ratio

Portland Cement: 1
Slag Cement = 0.82
Fine aggregate = 1.68
Coarse aggregate = 3.62
Water = 0.57
Superplasticizer = 0.00451

CONCRETE MIX DESIGN (GRADE M50)

DESIGN STIPULATION:

- Specific gravity of cement = 3.15
- Specific gravity of fine aggregate (F.A) = 2.6
- Specific gravity of Coarse aggregate (C.A) = 2.64
- Dry Rodded Bulk Density of fine aggregate = 1726 kg/m^3
- Dry Rodded Bulk Density of coarse aggregate = 1638 kg/m^3

Step-1: Select Concrete Target Strength, Slump, and Maximum Nominal Aggregate size:

- Target strength = 1.10 * 7252 + 700 = 8677 PSI = 59.8 MPa *From ACI 211.4R-08 Equation 3-3*
- Slump = 25 mm to 50 mm before using Superplasticizer *from ACI 211.4R-08 Table 6.1*

- Max size of aggregate used = 25 mm *From ACI 211.4R-08 Table 6.2*

Step-2: **Calculation for weight of Coarse Aggregate:**

- Fractional volume of oven dry Rodded C.A for 25 mm size aggregate = 0.75m^3 *From ACI 211.4R-08 Table 6.3*
- Weight of C.A = 0.75*1638 = 1228.5 kg/m^3

Step-3: **Calculation for Quantity of Water and Entrapped Air:**

- Assuming Slump as 25 to 50mm and for C.A size 25 mm the Mixing water = 166 kg/m3 *From ACI 211.4R-08 Table 6.3*
- Entrapped air Content: 1.0
- Void content of FA for this mixing water = 35%
  Void content of FA (V)
  V = {1-(Dry Rodded unit weight / specific gravity of FA*1000)}*100 *From ACI 211.4R-08 Equation 6-2*
  = [1-(1726/2.6*1000)]*100
  = 34.62%
- Adjustment in mixing water = (V-35) * 4.55 *From ACI 211.4R-08 Equation 6-3*
  = (34.62 – 35)*4.55
  = -1.725 kg/m3
  Total water required = 166 + (-1.725) = 164.28 kg/m3

Step-4: **Calculation for weight of cement:**

- Take W / C ratio = 0.36 *By interpolation from ACI 211.4R-08 Table 6.5*
- Weight of cement = 164.28 / 0.36 = 456.33 kg/m^3

Step-5: **Calculation for weight of Fine Aggregate:**

- Cement = 456.33 / 3.15*1000= 0.1449m^3
  Water = 164.28 / 1*1000= 0.16428 m^3
  CA = 1228.5 / 2.64*1000= 0.465 m^3
  Entrapped Air = 1 / 100= 0.010 m^3
  Total = 0.7842 m^3
- Volume of Fine Aggregate= 1-0. 7842= 0.216
- Weight of Fine Aggregate= 0.216*2.6*1000= 561.6 kg/m^3

Step-6: Super plasticizer:
For 0.8% = (0.8 / 100)* 164.28 = 1.314 kg/ m^3

Step-7: **Correction for water:**
Weight of water (For 0.8%) =164.28 – 1.314 = 162.966 kg/m^3

Requirement of materials per Cubic meter

Cement = 456.33 kg/m^3
Fine Aggregate = 561.6 kg/m^3
Coarse Aggregate = 1228.5 kg/m^3
Water = 162.966 kg/ m^3
Superplasticizer = 1.314 kg/ m^3

The final ratio

Cement: 1
Fine aggregate (kg/m^3): 1.23
Coarse aggregate (kg/m^3): 2.69
Water (l/m^3): 0.36
Superplasticizer = 0.00288

CONCRETE MIX DESIGN (GRADE M50) with Fly ASH C 35% Replacement

DESIGN STIPULATION:

- Specific gravity of cement = 3.15
- Specific gravity of fine aggregate (F.A) = 2.6
- Specific gravity of Coarse aggregate (C.A) = 2.64
- Specific gravity of Fly Ash Type C = 2.64
- Dry Rodded Bulk Density of fine aggregate = 1726 kg/m^3
- Dry Rodded Bulk Density of coarse aggregate = 1638 kg/m^3

Step-1: Select Concrete Target Strength, Slump, and Maximum Nominal Aggregate size:

- Target strength = 1.10 * 7252 + 700 = 8677 PSI = 59.8 MPa *From ACI 211.4R-08 Equation 3-3*
- Slump = 25 mm to 50 mm before using Superplasticizer *from ACI 211.4R-08 Table 6.1*
- Max size of aggregate used = 25 mm *From ACI 211.4R-08 Table 6.2*

Step-2: **Calculation for weight of Coarse Aggregate:**

- Fractional volume of oven dry Rodded C.A for 25 mm size aggregate = 0.75m^3 *From ACI 211.4R-08 Table 6.3*
- Weight of C.A = 0.75*1638 = 1228.5 kg/m^3

Step-3: Calculation for Quantity of Water and Entrapped Air:

- Assuming Slump as 25 to 50mm and for C.A size 25 mm the Mixing water = 166 kg/m3 *From ACI 211.4R-08 Table 6.3*
- Entrapped air Content: 1.0
- Void content of FA for this mixing water = 35%
  Void content of FA (V)
  V = {1-(Dry Rodded unit weight / specific gravity of FA*1000)}*100 *From ACI 211.4R-08 Equation 6-2*

= [1-(1726/2.6*1000)]*100
= 34.62%

- Adjustment in mixing water = (V-35) * 4.55 *From ACI 211.4R-08 Equation 6-3*
  = (34.62 – 35)*4.55
  = -1.725 kg/m3
  Total water required = 166 + (-1.725) = 164.28 kg/m3

Step-4: **Calculation for weight of cement:**

- Take W / C ratio = 0.36 *By interpolation from ACI 211.4R-08 Table 6.5*
- Weight of cement = 164.28 / 0.36 = 456.33 kg/m^3

Step-5: **Fly Ash :**

For 35% Fly ASH Class C = 0.35*456.33 = 159.72 kg/m^3 *from ACI 211.4R-08*
Portland Cement = 456.33– 159.72 = 296.61 kg/m^3 *from ACI 211.4R-08*

Step-6: **Calculation for weight of Fine Aggregate:**

- Cement = 296.61 / 3.15*1000= 0.0942 m^3
  Fly Ash = 159.72 / 2.64*1000 = 0.0605 m^3
  Water = 164.28 / 1*1000= 0.16428 m3
  CA = 1228.5 / 2.64*1000= 0.465 m3
  Entrapped Air = 1 / 100= 0.010 m3
  Total = 0.79398 m3
- Volume of Fine Aggregate= 1-0.79398 = 0.206 m^3
- Weight of Fine Aggregate= 0.206*2.6*1000= 535.6 kg/m^3

Step-6: Super plasticizer:
For 0.8% = (0.8 / 100)* 164.28 = 1.314 kg/ m^3

Step-7: **Correction for water:**
Weight of water (For 0.8%) =164.28 – 1.314 = 162.966 kg/m^3

Requirement of materials per Cubic meter

Cement = 296.61 kg/m^3
Fly Ash = 159.72 kg/m^3
Fine Aggregate = 535.6 kg/m^3
Coarse Aggregate = 1228.5 kg/m^3
Water = 162.966 kg/ m^3
Superplasticizer = 1.314 kg/ m^3

The final ratio

Cement: 1
Fly Ash = 0.54
Fine aggregate = 1.81

Coarse aggregate = 4.14
Water = 0.55
Superplasticizer = 0.00443

CONCRETE MIX DESIGN (GRADE M50) with Slag Cement 45% Replacement

DESIGN STIPULATION:

- Specific gravity of cement = 3.15
- Specific gravity of fine aggregate (F.A) = 2.6
- Specific gravity of Coarse aggregate (C.A) = 2.64
- Specific gravity of Slag Cement = 2.85
- Dry Rodded Bulk Density of fine aggregate = 1726 kg/m^3
- Dry Rodded Bulk Density of coarse aggregate = 1638 kg/m^3
- *Grade 100 Slag Cement will be used from ACI 211.4R-08 figure 8.3 and 8.4*

Step-1: <u>Select Concrete Target Strength, Slump, and Maximum Nominal Aggregate size:</u>

- Target strength = 1.10 * 7252 + 700 = 8677 PSI = 59.8 MPa *From ACI 211.4R-08 Equation 3-3*
- Slump = 25 mm to 50 mm before using Superplasticizer *from ACI 211.4R-08 Table 6.1*
- Max size of aggregate used = 25 mm *From ACI 211.4R-08 Table 6.2*

Step-2: <u>Calculation the portion of the required average compressive strength Fcr, regulated to Portland cement:</u>

- *The maximum relative compressive strength of the plain Portland cement mixture should be 114% based on figure 8.4*
- *Pc(psi)= fcr*100/(sci%) = 8677*100/114 = 7611.4 PSI = 52.4* MPa *from ACI 211.4R-08 figure 8.3 and 8.4*

<u>Calculation for weight of Coarse Aggregate:</u>

- Fractional volume of oven dry Rodded C.A for 25 mm size aggregate = 0.75m^3 *From ACI 211.4R-08 Table 6.3*
- Weight of C.A = 0.75*1638 = 1228.5 kg/m^3

Step-3: <u>Calculation for Quantity of Water and Entrapped Air:</u>

- Assuming Slump as 25 to 50mm and for C.A size 25 mm the Mixing water = 166 kg/m3 *From ACI 211.4R-08 Table 6.3*
- Entrapped air Content: 1.0
- Void content of FA for this mixing water = 35%
  Void content of FA (V)
  V = {1-(Dry Rodded unit weight / specific gravity of FA*1000)}*100 *From ACI 211.4R-08 Equation 6-2*
  = [1-(1726/2.6*1000)]*100
  = 34.62%

- Adjustment in mixing water = (V-35) * 4.55 *From ACI 211.4R-08 Equation 6-3*
  = (34.62 – 35)*4.55
  = -1.725 kg/m3
  Total water required = 166 + (-1.725) = 164.28 kg/m3

Step-4: **Calculation for weight of cement:**

- Take W / C ratio = 0.36 *By interpolation from ACI 211.4R-08 Table 6.5*
- Weight of cement = 164.28 / 0.36 = 456.33 kg/m^3

Step-5: **Amount of Slag Cement :**

For 45% Slag Cement = 0.45*456.33 = 205.35 kg/m^3 *from ACI 211.4R-08 the maximum strength point based on figure 8.4 lies in 45% Slag Cement Content*

Portland Cement = 456.33 – 205.35 = 250.98 kg/m^3 *from ACI 211.4R-08*

Step-6: **Calculation for weight of Fine Aggregate:**

- Portland Cement = 250.98 / 3.15*1000= 0.0797 m^3
  Slag Cement = 205.35/ 2.85*1000 = 0.0721 m^3
  Water = 164.28 / 1*1000= 0.16428 m3
  CA = 1228.5 / 2.64*1000= 0.465 m3
  Entrapped Air = 1 / 100= 0.010 m3
  Total = 0.79108 m3
- Volume of Fine Aggregate= 1-0.79108 = 0.20892 m^3
- Weight of Fine Aggregate= 0.20892 *2.6*1000= 543.2 kg/m^3

Step-7: Super plasticizer:
For 0.8% = (0.8 / 100)* 164.28 = 1.314 kg/ m3

Step-8: **Correction for water:**
Weight of water (For 0.8%) =164.28 – 1.314 = 162.966 kg/m3

Requirement of materials per Cubic meter
Portland Cement = 250.98 kg/m^3
Slag Cement = 205.35 kg/m^3
Fine Aggregate = 543.2 kg/m^3
Coarse Aggregate = 1228.5 kg/m^3
Water = 162.966 kg/ m^3
Superplasticizer = 1.314 kg/ m^3

The final ratio

Portland Cement: 1
Slag Cement = 0.82
Fine aggregate = 2.16
Coarse aggregate = 4.89
Water = 0.65
Superplasticizer = 0.00524