Ain Shams University
Egypt

Exploring Opportunities to Improve Benefit-Cost Ratio of Office Buildings' Energy Efficiency Technology Applications (EETA) in Egypt

A Thesis submitted in the Partial Fulfillment for the Requirement of the Degree of Master of Science in Integrated Urbanism and Sustainable Design
by
Mennatullah Mohamed Mahmoud AbdelGawad

Supervised by

Prof. Mohamed Salheen
Professor of Integrated Planning & Design
Ain Shams University

Assoc. Prof. Danae Hernandez-Cortes
Professor of Future of Innovation in Society
Arizona State University

Assoc. Prof. Khaled Tarabieh
Professor of Architecture
American University in Cairo

24 July 2023

Exploring Opportunities to Improve Benefit-Cost Ratio of Office Buildings’ Energy Efficiency Technology Applications (EETA) in Egypt

A Thesis submitted in the Partial Fulfillment
for the Requirement of the Degree of Master of Science
in Integrated Urbanism and Sustainable Design

by Mennatullah AbdelGawad

Supervised by

Prof. Mohamed Salheen
Professor of Integrated Planning & Design
Ain Shams University

Assoc. Prof. Khaled Tarabieh
Professor of Architecture
American University in Cairo

Assoc. Prof. Danae Hernandez-Cortes
Professor of Future of Innovation in Society
Arizona State University

Examiners Committee
Title, Name & Affiliation

Signature

Prof.
Professor of
University of

Prof.
Professor of
University of

Prof.
Professor of
University of

Prof.
Professor of
University of

Ain Shams University
Egypt

07/24/2023

Disclaimer

This dissertation is submitted to Ain Shams University (ASU) and University of Stuttgart - Faculty of Architecture and Urban Planning (USTUTT) for the degree of Integrated Urbanism and Sustainable Design (IUSD), in accordance to IUSD-ASU regulations.

The work included in this thesis was carried out by the author during the period from February - July 2023.

The author confirms that the work submitted is his/her own and that appropriate credit has been given where reference has been made to the work of others. Any disputes regarding the copy right of the content is the sole responsibility of the author.

Ain Shams University holds the right to publicly distribute this thesis in the current university standard format. The author holds the right to publish the content in any other format.

07/24/2023

Mennatullah AbdelGawad

Signature

Aknowledgment

Reaching this milestone is huge for me and I wouldn’t have made it without the blessings of Allah and the love and support of all people around me. Therefore, I would like to express my gratitude to all who supported me during this journey.

First, I would like to thank my parents, Samar and Mohamed, for their continuous support and encouragement. They were always pushing me towards development and improvement. My brothers, Mahmoud and Marawan, were also of great support and help. Thank you all for providing me with an encouraging environment.

Second, I would like to thank my supervisors, Dr. Salheen, Dr. Danae, and Dr. Khaled, for their support and very helpful input and feedback. Dr. Salheen has been a great mentor during these past two years, always pushing me toward my best self. Dr Danae added so much to my knowledge by helping me get the proper exposure to helpful resources and sharing her extensive knowledge with me. She was also very welcoming and supportive during my exchange semester at Arizona State University.

Dr. Khaled’s technical feedback and his sharing of beneficial sources have been a great help to me and this study. In addition, I would like to thank my friends who were always there whenever I needed any kind of help and who were sources of inspiration to me throughout my journey.

Last but not least, I would like to extend my gratitude to my company, Hassan Allam Holding, and its CEOs, Eng. Hassan and Eng. Amr, for their encouragement and motivation. Their support helped me accomplish this milestone while working full-time on my dream job.

Exploring Opportunities to Improve Benefit-Cost Ratio of Office Buildings' Energy Efficiency Technology Applications (EETA) in Egypt

Mennatullah AbdelGawad

Abstract

The building sector consumes a high percentage of the world's and Egypt's energy consumption (30% and 50% respectively). The building sector in Egypt has much potential to decrease its consumption and be more energy efficient. Energy Efficient Technology Applications (EETAs) have been used in several buildings to produce energy savings and reduce the building's carbon footprint. In Egypt, as in many other countries, the EETAs are notorious for their high initial cost, which makes them not the first choice for many developers. In addition, due to a gap of knowledge in finding ways to reduce Office Building EETA initial costs while increasing its benefit in Egypt, it is hard to accelerate the slow increase of Energy Efficient Buildings in Egypt.

This study explores potential opportunities for improving the benefit-cost of these EETAs and highlights ways to reduce the EETAs' initial cost and increase their benefits. It also provides a ranking for the EETAs based on their affordability and savings in office buildings in Egypt. This would help identify the bottlenecks that hinder the increase of EETAs' adoption in buildings and would help guide developers and tenants toward the affordable EETAs that would accomplish their desired savings based on their building size.

This study uses three public and free software: EDGE, Build_Me, and eQuest for the EETAs energy simulation. Three hypothetical office building sizes were chosen to conduct the simulations on. The incremental cost of each EETA was calculated based on their market price. Then the savings and cost results were used to calculate the Net Present Value of each EETA and categorize them according to their low/high cost and low/high savings. The study results show that the cooling systems, the wall insulation, and the light controls are EETAs with high-cost, high-savings and they are the most worthy of further improvements to decrease their cost and further increase their benefit. The study also shows that the energy-efficient light bulbs and reduced Window to Wall ratio have low cost and produce high savings, so they could be directly used in buildings in Egypt for better energy performance.

Key Words: Energy Efficiency, Cost Benefit, Energy Efficient Technology Applications, Office Buildings

Table of Content

List of Figures

List of Tables

Chapter 1: Introduction and Background

Recent and past human behaviors and decisions have led us to severe problems that could risk our survival. Our most prominent issue, for example, is climate change. The world is suffering from the excess of Green House Gas emissions that have been mostly intensified due to the burning of fossil fuels for humans' energy supply. The energy market has been for years dominated by a few major stakeholders whose decisions, according to IEA, have led to a global energy crisis. The current energy crisis is caused mainly by the Russian-Ukrainian war. As Russia has been one of the world's biggest providers of energy, because of the war, the world has been suffering from a shortage in energy supply.

The current energy crisis has made the whole world realize that we need a more resilient energy infrastructure that depends more on renewables rather than imported fossil fuels. Energy efficiency has also been a huge topic of discussion for two reasons. The first is to decrease overall demand to not build energy plants with huge capacities. The second is to reduce our carbon emissions since most of the large countries have committed to net-zero emissions by 2050. In that sense, many international agencies have analyzed the world's energy consumption to begin working on the consumption reduction of each sector.

Countries are currently trying to solve the energy crisis and mitigate climate change by building more renewable energy plants, investing more in energy efficiency, revising old energy policies, and writing new ones to ensure a successful energy transition. Most countries have been setting ambitious goals of reaching 100% of energy sourcing from renewables by 2050. Egypt, for example, has set in a 42% renewable energy sourcing goal by 2035. For that transition to be successful and these goals to be met, all sectors should work towards reducing their energy consumption and using renewable sources for their energy.

Energy Efficiency, which is the use of less amount of energy to conduct the same work, has been found by many to be one of the most effective solutions that could help in solving the energy crisis and climate change. As the building sector consumes nearly 30% of the world's energy and 50% of Egypt's energy, it is important for our buildings to be more energy efficient.

1.1 Global Energy Supply Problem

Energy markets are extremely volatile due to geopolitical unrest and a rise in energy demand, even though governments and corporations are increasingly committed to strict decarbonization targets. Given the uncertainty surrounding supply security and affordability, the conflict in Ukraine and other factors have caused huge price spikes in energy. This occurs at a time when the markets are already constrained as a result of the COVID-19 recovery. Global energy demand and emissions rose by 5% in 2021 compared to 2020, approaching pre-COVID-19 levels (around 33 Gt of energy-related CO2 equivalent). (McKinsey Energy Insights Global Energy Perspective, 2022)

Natural gas prices rose to record levels, which in turn caused power prices to rise in some areas. Since 2008, Oil has reached its highest prices. The cost of energy has increased, which has led to excruciatingly high inflation, pushed households into poverty, forced some factories to reduce output or even close, and delayed economic growth to the point where several nations are on the verge of a catastrophic recession. (IEA, 2022)

According to Etienne Gabel from S&P Global Commodity (2022), there are two main problems in the global energy sector: increasing energy prices that causes an affordability crisis and a lack of energy sources (especially fossil fuels) that creates an energy supply crisis. Rising energy costs have exacerbated extreme poverty and slowed progress toward attaining universal and affordable energy access in developing and emerging economies, where the share of household expenditures spent on energy and food is already significant. Even in developed

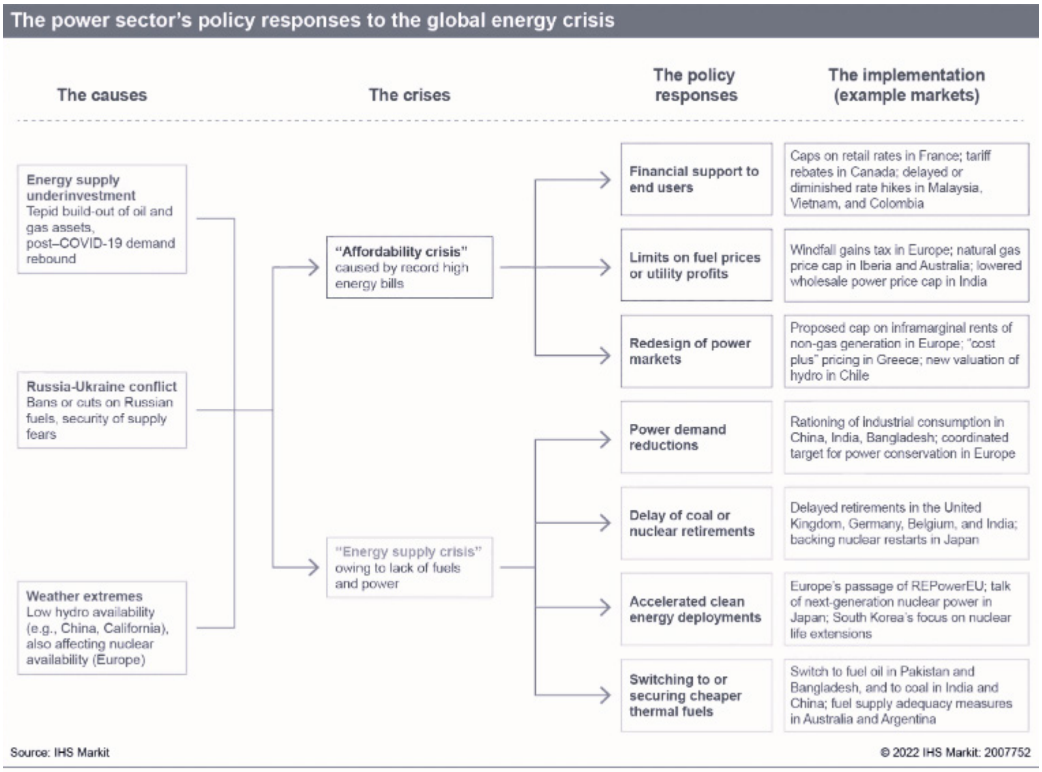


Figure 1: The Power Sector's Policy responses to the global energy crisis (IHS Markit, 2022 as mentioned in Gabel, 2022)

countries, the high energy prices have caused large social, economic, and political hindrances. (IEA, 2022)

1.11 Cause

The worldwide design of many power markets is being put to the test by the current energy crisis. Two pressing and interconnected crises (affordability and energy supply crisis) are emerging for policymakers to address due to underinvestment in conventional energy infrastructure, the post-COVID-19 economic recovery earlier this year, the conflict in Ukraine and Russia's obstruction of gas supplies to Europe, and significant climatic events (like water shortages in mainland China and Europe), see figure 1. (Gabel, 2022)

Russia is the largest supplier of oil and gas in the world, and the main supplier to Europe. Numerous penalties were imposed on Russia by the EU and the US, and many European nations stated their desire to fully stop importing

Russian gas. In parallel, Russia has gradually reduced or even shut down its export pipelines. Consequently, the EU raised the prices of ship-born liquified natural gas (LNG) coming from US Australia, and Qatar. As gas is mainly the price setting factor of electricity, power prices raised as well. (IEA, 2022)

1.12 Existing Efforts toward a solution

Many countries are trying to mitigate the energy prices increase on consumers by either subsidizing electricity, fixing energy prices and paying suppliers the difference, or providing direct assistance to consumers. However, because many countries currently are suffering from inflation and have spent huge sums of their budgets on COVID-19 emergencies, the capacity for cushioning the effect of high energy prices is limited. (IEA, 2022)

In liberalized markets like Europe, Canada, and Australia, new regulations addressing the affordability dilemma have become popular. These laws, for instance, capped fuel prices or end-user power rates. This fact makes sense because, to put it simply, retail prices in liberalized markets often reflect (at least in part) the marginal cost of production, whereas, in closed markets, the tariffs are related to the mean generation costs or are otherwise significantly subsidized. Affordability regulations were also passed in developing countries: mainland China has long limited the price of fuels for power generation, while recent power tariff increases in Colombia, Thailand, and Indonesia were reduced or slowed. Power rationing, delayed thermal retirements, or switching to less expensive but dirtier thermal fuels are common solutions in markets with rising demand and where prices are frequently a concern (e.g., mainland China, India, Bangladesh). (Gabel, 2022)

Europe is seeking gas importing from other countries including Algeria, Norway, and Azerbaijan. Several governments have increased or resumed using coal to generate electricity, while several are extending the lifespan of nuclear power reactors that are about to be decommissioned. Additionally, EU nations have imposed requirements for gas storage and established voluntary goals to decrease gas and electricity demand by 15% this winter through efficiency methods, increased use of renewable energy sources, and aid for efficiency improvements. (IEA, 2022)

In the framework of COP26, 64 nations in total (representing 89% of the world’s CO2 emissions) have announced net-zero commitments, while financial institutions and private sector businesses also continue to raise their decarbonization objectives. (McKinsey Energy Insights Global Energy Perspective, 2022)

1.13 Needed Efforts toward a solution.

Like how the oil shocks of the 1970s led to significant advancements in energy efficiency, nuclear, solar, and wind power, the current crisis may hasten the deployment of cleaner, sustainable renewable energy such as wind and solar. The crisis has also highlighted how crucial it is to spend money on a reliable gas and power network infrastructure to effectively integrate regional markets. Both the Inflation Reduction Act of the United States, passed n August 2022, and the EU's RePowerEU, proposed in May 2022, feature significant steps to advance energy efficiency and encourage renewable energies. (IEA, 2022)

The world's desire to decarbonize within the next 25 to 30 years serves as the backdrop to the current energy crisis. Today's strategies are either opportunistic (e.g., mainland China and India obtaining cheap gas from Russia) or survivalist (e.g., Europe increasing its reliance on renewable energy), which may necessitate further reorganization of the global power markets in the future. As geopolitics alters how governments manage energy security, affordability, and the energy transition, market designs will change. Players in this space will face policy risks as a result of this. (Gabel, 2022)

All scenarios call for significant changes in the global energy system. To launch new technologies, large investments will probably be needed, even under the Current Trajectory scenario. The global energy system may need to transition substantially more quickly than even the declared net-zero pledges, moving away from oil and gas toward efficiency, electrification, and new fuels, to maintain the 1.5° Pathway. (McKinsey Energy Insights Global Energy Perspective, 2022)

To decarbonize heavy industries where fossil fuels continue to play a substantial role, two to four Gt of CO2 will need to be absorbed by CCUS by 2050. By 2050, it is expected that the world's need for electricity will have tripled as more industries electrify themselves and as decarbonization increases demand for hydrogen and hydrogen-based fuels. By 2050, it is anticipated that renewable energy sources would account for 80–90% of the world's energy consumption as global build-out rates for solar and wind energy increase by a factor of 5 and 8, respectively. (McKinsey Energy Insights Global Energy Perspective, 2022)

1.14 Egypt Energy Situation

Despite the numerous challenges it experienced for years, Egypt's energy sector has recently emerged as a desirable place for investment. Considering that Egypt experienced the biggest energy crisis in its modern history from 2009 to 2013, the sector is doing better and better, generating a radically different position than six years ago. (Alhoseiny, 2021)

During Egypt's Electricity crisis, the power outage was frequent and occurred for long hours. Due to population growth and changes in the industrial sector, the crisis occurred at a period when there was a lar level of domestic demand. Egypt's energy capacity was unable to meet these needs because of long-term mismanagement of the energy and natural gas production files as well as political unrest during the revolution. In that period, Egypt's natural gas was not well distributed which caused the country to suffer from an energy crisis. By 2014, stability had returned to the nation, and the new leadership took the issue seriously and implemented both immediate and long-term fixes. (Alhoseiny, 2021)

As a short-term solution, the amount of gas going to cement, and fertilizer companies was reduced from 940 million cubic feet per day to 350 million cubic feet per day. This gas was then routed to power plants, which reduced the gap between supply and demand to 1,800 megawatts. The amount spent on energy subsidies was reduced by about a third, and the price of power gradually increased by 30 to 55 percent, depending on the usage category. (Alhoseiny, 2021) For the long-term solution, investors were invited to build new power plants in Egypt. Most of the planned to build power plants are renewable sources to help achieve Egypt's target of 42% renewable energy sourcing by 2035.

Egypt's energy sector has been affected by the Energy Crisis caused by the Russian and Ukrainian wars. Unlike Europe, it has not been affected by a deficit of fuel, but rather, it was affected economically. Since the war, Egypt has suffered from increased oil prices and high inflation rates. The Central Bank of Egypt decided to increase interest rates by 1% in March and subsequently by 2% in May to lessen their detrimental effects on the Egyptian economy. However, since Egypt is one of the major LNG and natural gas exporters in the world, it produced 58.5 bcm in 2022, ranking 14th among all natural gas producers worldwide, fifth regionally, and second in Africa. Particularly for Europe, Egypt has the potential to become a major regional energy hub. (Monsef et al., 2022)

In addition, Russia and Egypt entered into several military and energy agreements that will be impacted by the war's development. The first nuclear power station in Egypt is being built and funded by Russia in Dabaa. These contracts and projects will probably be disrupted as a result of the ongoing conflict in Ukraine and the severity of the sanctions imposed on Russia. (Al-Anani, 2022)

Along with the high and raising energy prices in Egypt, it has a high GHG emission (271 Mt CO2e in 2019) from the energy sector caused by the dependence on fossil fuels for 85-90% of its energy supply. Egypt had a target of reaching 20% renewable energy sourcing in 2022, but it didn't achieve it. This makes its next target of 42% in 2035 very challenging to achieve.

Nevertheless, Egypt has started several energy structural adjustments, lowering power subsidies gradually and enacting feed-in tariffs to encourage the generation of renewable energy. The country's recent energy sector reforms have increased investments significantly, which has increased electricity output over the past five years and ensured a consistent supply across the nation. (IEA, 2022)

1.2 Global Energy Demand

To help solve the global energy crisis, mitigate climate change, and avoid future energy and climate problems, further understanding of the world's energy consumption is needed to help make energy use more efficient and to build more optimized energy sources.

Global energy consumption has grown by nearly a third since 2000, and it is expected to keep rising soon. Global energy demand increased by 2.9% in 2018, and under a status quo forecast, by 2040, consumption will have increased by a further 30% to 740 million terajoules. This will result in a rise in worldwide energy consumption of 77 percent from 2000 to 2040. (The World Counts, 2022)

1.21 Energy Consumption by Energy Source

Unlike before, today there are several energy sources around the world: gas, oil, coal, nuclear, hydropower, renewables, etc. The consumption from each source varies according to its availability, its capacity, and location. In Figure 2, it could be observed that conventional biomass, or the burning of solid fuels like wood, crop waste, or charcoal, was the world's main source of energy up until the middle of the 19th century. However, the rise of coal, then of oil and gas, and by the beginning of the 20th century, hydropower, coincided with the Industrial Revolution. (Ritchie et al., 2022a)

Oil is the source of the most energy consumed worldwide, followed by coal, gas, and hydroelectricity. More than 80% of energy is consumed by fossil fuels. The combustion of fossil fuels for energy is responsible for almost three-quarters of all worldwide greenhouse gas emissions. (Ritchie et al., 2022). In 2021, primary energy increased by 31 EJ, which was the highest growth ever recorded and more than offsetting the significant loss witnessed in 2020. In 2021, 8 EJ more primary energy was produced than in 2019. Emerging economies,

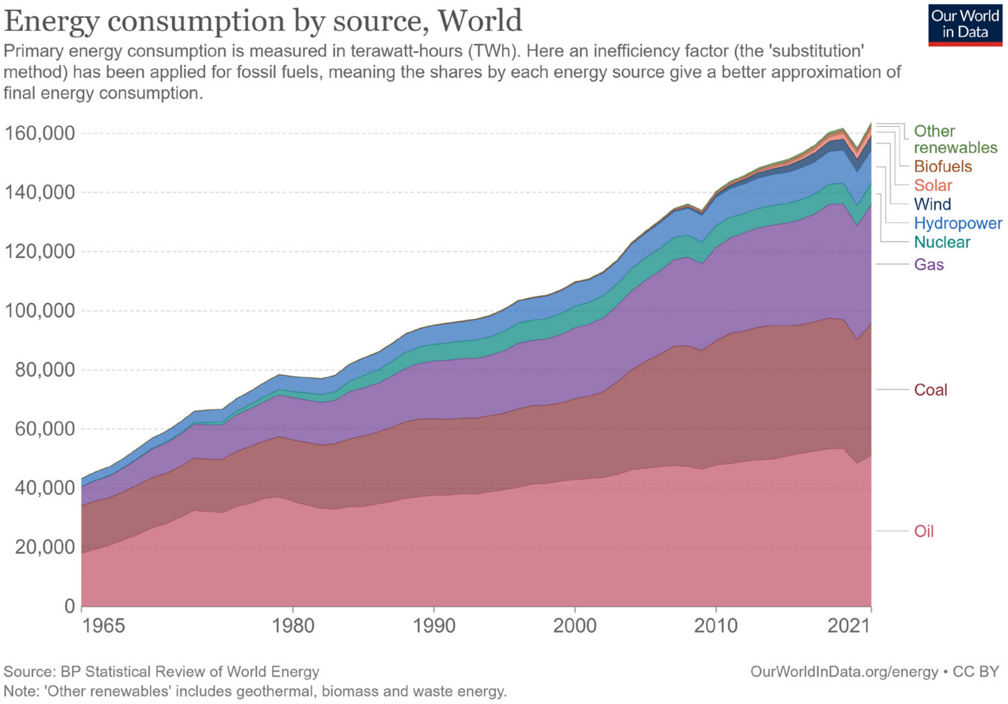


Figure 2: World Energy Consumption by source (Ritchie et al., 2022)

which expanded by 13 EJ, led to an increase in primary energy in 2021, with China expanding by 10 EJ. See Figure 3 (bp global, 2022)

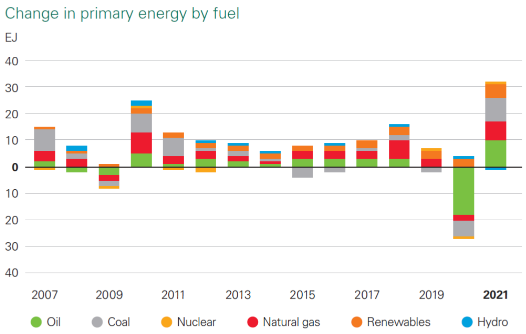


Figure 3: Change in primary energy by fuel. (bp global, 2022)

Renewable energy sources were solely responsible for the growth in primary energy between 2019 and 2021. Between 2019 and 2021, the amount of fossil fuel energy consumption remained constant, with increasing natural gas (5 EJ) and coal (3 EJ) consumption offsetting decreasing oil demand (-8 EJ). (bp global, 2022)

1.22 Energy Consumption per Sector

According to the International Energy Agency (IEA), the final consumption of electricity worldwide in 2019 was 22 848 TWh, up 1.7% from the previous year. The final consumption of electricity in Organization for Economic Co-operation and Development (OECD) nations[1] was 9 672 TWh in 2019, which was 1.1% less than in 2018, while the final consumption in non-OECD countries was 13 176 TWh, which was 3.8% more than in 2018. See Figure 4.

Since 1974, the residential, commercial, and public service sectors have accounted for most of the growth in the OECD's power consumption. As a result of the long-term reduction in the industry's consumption share, these three sectors now account for about equal amounts of consumption as of the year 2019. Transport, agriculture, and fishing are the only remaining consuming sectors that use relatively little electricity. However, as electric vehicles gain market share throughout OECD countries, particularly in Europe, road transportation has recently seen a rapid increase. Outside of the OECD, industry dominates the usage of electricity, accounting for half of total consumption. (IEA, 2019)

---

[1] OECD Countries: Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, SWEDEN, Switzerland, Turkey, United Kingdom, and United State.

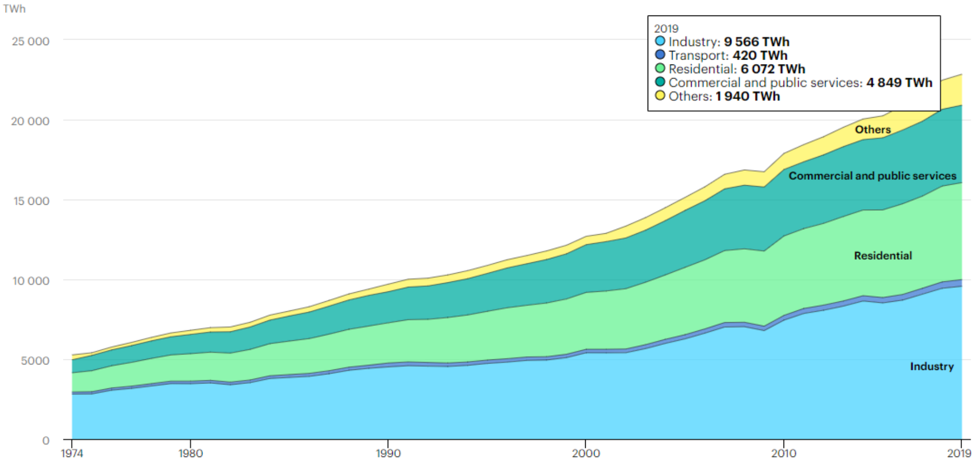


Figure 4: Energy Consumption by sectors (IEA, 2019)

1.23 Projections

A decade of rapid expansion for natural gas is coming to an end due to high energy prices, increased energy security concerns, and tightened climate rules; in the Stated Policies Scenario (STEPS)[2], its annual demand growth slows to 0.4% from now to 2030, down from 2.3% from 2010 to 2019. As a result of rising natural gas prices, coal temporarily experiences a surge in demand from the power and industrial sectors in some regions. However, as soon as steps were taken to reduce emissions, coal demand began to decline once more, and by the end of the decade, it was 9% lower than it was today. The fastest-growing energy sources this decade are renewables, particularly solar PV and wind, which will generate 43% of the world's electricity in 2030 compared to 28% currently. (IEA, 2022)

Over the decade leading up to 2030, primary energy intensity increases by 2.4% per year. By 2030, electricity will account for 22% of all final use in the STEPS, up from 20% in 2021. Building energy consumption increased in the STEPS by 3% by the end of the decade compared to 2021, driven by an increase in floor space overall and an increase in appliance ownership in emerging markets and developing economies. By 2030, the energy demand for buildings in the Announced Pledges Scenario (APS)[3] is around 10% lower than in the STEPS and fall by 8% from current levels. As people move to use cleaner cooking methods and more efficient stoves and fuels, conventional biomass consumption will

---

[2] STEPS: Scenario modeling entity

[3] APS: Scenario modeling entity

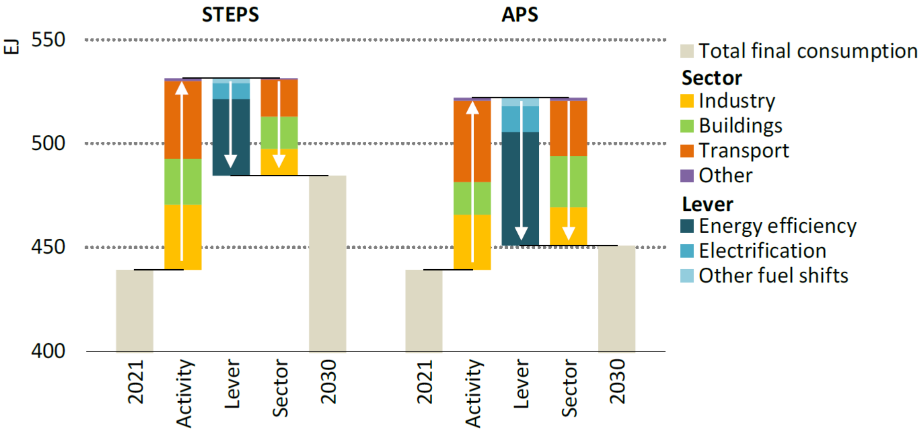
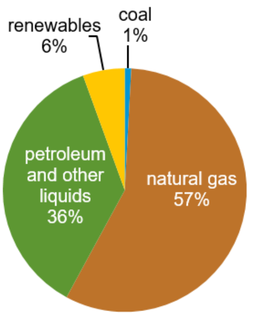


Figure 5: Changes in global final energy consumption by lever and sector in the STEPS and APS, 2021-2030 (IEA, 2022)

decline by 15 EJ by 2030, contributing to the divergence from the STEPS. (IEA, 2022) See Figure 5.

1.24 Egypt's Energy Consumption

In 2021, Egypt consumed 9,646 TWh of energy, 202.25 TWh of which were electricity; that is 7.14% more than the energy consumed in 2020. (Ritchie et al., 2022b). According to BP's 2021 Statistical Data, 57% of Egypt's energy consumption comes from natural gas, 36% from oil, 1% from coal, and 6% from renewables (wind, solar, and hydro) (EIA, 2022). The most electricity-consuming sector, according to both IEA and the Egyptian Electricity Holding



Source: Graph by the U.S. Energy Information Administration, based on data from BP's *2021 Statistical Review of World Energy*

Figure 6: Primary Energy Consumption in Egypt 2020 (EIA, 2022)

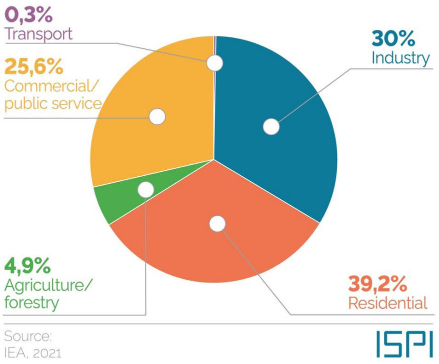


Figure 7: Electricity Consumption by Sector in Egypt (ISPI, 2022)

Company (EEHC), is the residential sector with almost 40% of the total electricity in Egypt. The other sectors that consume a relatively large percentage of electricity in Egypt are industry 30%, and Commercial 25.5%. See Figure 6 & 7.

Egypt's energy consumption has a carbon intensity of 464 gCO2e per kWh of energy (Ritchie et al., 2022) which is lower but close to the world's average carbon intensity of 475 gCO2e per kWh (IEA, 2019). That is because 94% of its energy comes from high-carbon sources and only 6% comes from low-carbon sources.

1.25 Energy Efficiency

Energy Efficiency is now sought as one of the few solutions to the energy crisis and climate change. Energy efficiency is the use of less energy to produce the same result. It is found an important tool for many economic and environmental reasons. It can be applied in different sectors and with a range of technologies. Today, most countries are targeting to decrease their energy intensity (energy consumption per Gross Domestic Product) through energy efficiency techniques.

Energy efficiency is different than energy conservation. Energy conservation is basically decreasing energy without reaching the same output or work. For example, turning the light off when it is not needed, this is energy conservation. An energy-efficient solution is to replace fluorescent bulbs with LED bulbs. (Yang and Yu, 2015)

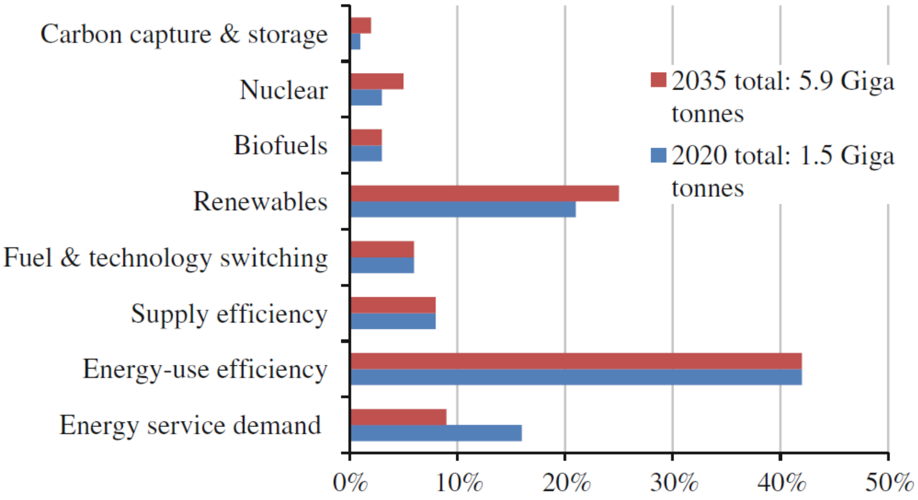


Figure 8: Projection of GHG emissions reduction by technologies (IEA, 2013 as cited in Yang and Yu, 2015)

1.26 Importance

Energy efficiency is one of the few ways that we can use to reduce our GHG emissions. In order to mitigate climate change impact, more effective methods should be taken to avoid energy loss. Energy-efficient technology helps in using all produced energy in work, avoiding energy waste. In that way, less energy is needed to be consumed, thus lower GHG emissions. According to IEA World Energy Outlook 2013, energy efficiency would be responsible for the reduction of 50% of CO2 emissions in 2035. See Figure 6. (Yang and Yu, 2015)

1.27 Challenges

As energy efficiency is perceived to have a high potential of mitigating climate change and aiding in the alleviation of any energy crisis, the implementation is facing several barriers. Energy Efficiency Gap is a term used in literature to describe the difference between the expected investments in energy efficiency and the actual lower number of investments. According to previous studies, this gap could be occurring because of economic, behavioral, and organizational aspects. (O’Malley et al., 2003).

Economic barriers to energy efficiency increase include several points that include non-market failures and market failure reasons. One example of a non-market barrier is heterogeneity, which means that the cost-effectiveness of a certain technology may vary based on its quantity and applied scale. (O’Malley et al., 2003) Other examples include Hidden costs, which means not considering other non-energy related costs, and Credit Constraints, which means that the consumer has no access to high capital costs that would allow investments in energy efficiency. (Cleary & Palmer, 2020) Also, the uncalculated risks of different economic trends and financing risks resemble a significant barrier to energy efficiency growth in the market. (O’Malley et al., 2003)

The economic barriers due to market failures include misplaced incentives. This appears when a landlord decides to buy cheap inefficient technology as it would be used and paid for its operation costs by the leasing tenants. In this case, the landlord would not benefit from the reduced operation cost as he/she would not have to pay for the utilities cost. A possible solution to this is shared utility contracts, which make the landlord pay part of the utilities cost. (Yang & Yu, 2016). A similar market failure economic barrier is the Principal-Agent Relationship. In this relationship, the “Principal” needs the “Agent” to fulfill a certain goal but the principal has little guarantee over the performance of the agent. An example of this would be in a company where the owner wants the employees to conserve energy, but he/she has no monitoring system to track their conservation. (O’Malley et al., 2003)

Other market failure economic hindrances include imperfect information and adverse selection. Imperfect information is basically not providing the energy efficiency data to the buyer and thus causing him/her not taking an informed purchase decision. Adverse selection is having the supplier know more information about the product than the buyer, like the energy performance or consumption, this leads to buyers taking decisions based on merely visible aspects like the cost. Having policies that ensure proper labeling is crucial to avoid these issues. (O’Malley et al., 2003)

As the economic barriers are very impactful, the behavioral factors are also affecting the increase of the energy efficiency gap. The external cost like the cost of harming the environment is rarely considered in the pricing process of technology and by the buyer. However, if taxes for pollution are imposed by the governments for inefficient products, the combined cost of the item and the environmental harms would surpass the cost of efficient equipment. (Yang & Yu, 2016) The social barriers also involve customer inertia, which is resistance to change. The buyer might have all the information available to him/her but still chooses to keep making old choices from the perspective of refusing to invest in the unknown. (O’Malley et al., 2003)

Increasing adoption of energy-efficient technology could also result in an increase in energy consumption. That is called the rebound effect; this effect happens when the decreased cost of operation makes us use the technology more. For example, a lower energy price of a high COP HVAC could encourage the user to turn on the HVAC more frequently. This leads to an overall increase in consumption (Cleary & Palmer, 2020)

Organizations and governance could have a huge effect on the Energy Efficiency Gap, as the buy-in of the top management could alter very impactful decisions. An organization that is driven by top management that believes in energy efficiency and energy conservation could lead to a change in culture for its members. On the contrary, the leadership of an individual who doesn’t prioritize efficiency in his/her decisions would lead to losses that influence several people involved in this entity. (O’Malley et al., 2003).

Chapter 2: Literature Review: Cost Benefit Analysis of Energy Efficiency in Buildings

2.1 Search Method

For the following literature review, a comprehensive online search for texts that focus on the cost-benefit of energy efficiency was made. In addition, references from found papers have been used for further review. Google Scholar and Scopus search engines have been used to find online-related text. The keywords used for search in both engines are "cost-benefit of energy efficiency in buildings" (all words included).

In Google Scholar the initial input of keywords has resulted in 1,520,000 texts. After changing the time frame to be from 2000 – 2023 (23 years old as a commonly accepted time frame for sourcing), the results were reduced to 17,800. Then the condition of having all keywords included in the title, the results were reduced to 10. Of the 10 results, 5 were papers and 5 were citations. The citations were eliminated as their pdf sources were not available. The resulting 5 papers' titles are listed below:

- Cost-benefit analysis for Energy Efficiency Retrofit of existing buildings: A case study in China (Liu and Ye, 2017)
- A cost-benefit analysis of hybrid energy efficiency application in buildings (Aravossis and Kapsalis, 2016)
- Financial evaluation of energy efficiency in buildings: Social cost-benefit analysis (Pinter, 2019)

- Application and Importance of Cost Benefit Analysis to Energy Efficiency Projects in Public Buildings: The Case of Serbia (Mihic et al., 2012)
- Possibilities of Application of Cost-Benefit Analysis to Energy Efficiency Projects in Buildings (Mihic et al., 2011)

Scopus search engine was also used in a similar filtering approach to the above Google Scholar's search approach. After the keywords "cost-benefit of energy efficiency in buildings" were inputted in Scopus, the results were 2,782 texts. The results were reduced to 895 texts after limiting the search to "open access" documents only. Then a limitation of having the keywords in the title of the text reduced the outputs to 3 papers. However, one paper (Application and Importance of Cost Benefit Analysis to Energy Efficiency Projects in Public Buildings: The Case of Serbia) was repeated from the Google Scholar search output. The remaining 2 papers' titles are mentioned below:

- Energy efficiency in multi-family residential buildings in Latvia. Cost-benefit analysis comparing different business models (Zvaigznitis et al., 2015)
- Modeling Energy Efficiency Performance and Cost-Benefit Analysis Achieving Net-Zero Energy Building Design: Case Studies of Three Representative Offices in Thailand (Lohwanitchai and Jareemit, 2021)

2.2 Paper 1:

Cost-benefit analysis for Energy Efficiency Retrofit of existing buildings: A case study in China (Liu and Ye, 2017)

The study was made in China on an actual residential project that has 4 buildings. The research problem was that Energy Efficiency Retrofit projects are not receiving interest from investors due to economic reasons. The aim of the research is to guide policy managers and makers to apply incentive systems and management techniques to promote the value of Energy Efficiency Retrofit Projects in China.

The methodology used is measuring cost-benefit analysis on an actual project rather than using regular simulation techniques. The EETA used in the building are mainly enhancements of heat sources (internal and external) and building envelopes (roof, external walls, and windows). For the cost-benefit analysis, Project Financial Evaluation Methods were used with Static Investment Payback

Period and Internal Rate of Return as indexes. The Net Profit Value, however, was not used because it requires a discount rate which is hard to calculate in this study. A sensitivity analysis was also performed to evaluate the additional effectivity of a method if the external factors (economic, political, social...etc.) were removed or lessened.

The Results of the study showed that the enhancement of heat sources and outdoor heating networks is effective from the cost-benefit perspective. However, envelope retrofitting is less effective; the windows' decrease in U-value is more cost-effective than increasing external wall insulation. The sensitivity analysis showed that energy pricing is the most sensitive factor and would increase the benefit-cost of EETA significantly if increased. The selection of the building materials used for the retrofitting is also a sensitive factor in increasing the benefit-cost of EETA. The cost of the EETA, however, is not relatively a sensitive factor to the increase of the benefit-cost ratio. The research of this paper is useful to be used to compare results, however, it was done in China which has different climatic conditions than Egypt. The study also did not use Net Present Value as a tool, which is crucial for this study's economic analysis.

2.3 Paper 2:

A cost-benefit analysis of hybrid energy efficiency application in buildings (Aravossis and Kapsalis, 2016)

The study was made on an experiment to combine PV and heat pump configuration systems. The research problem is that the PV system has a very high cost and its performance is affected by environmental conditions. The aim of the research is to analyze the possibility of increasing the efficiency of the PV system by comparing a hybrid PV-heat pump system to a conventional system. The idea is to capture the excess waste energy from the PV panels and recover it into the heat pump system.

The method used for analysis is the cost-benefit analysis of Net Present Value calculations. The results show that the hybrid system is more cost-effective than the conventional system as less energy is lost. The paper's economic evaluation of the EETA is near to the method used by this study, however, the paper only focuses on one or two EETAs instead of the ten EETAs that this study analyzes.

2.4 Paper 3:

Financial evaluation of energy efficiency in buildings: Social cost-benefit analysis (Pinter, 2019)

The main issue targeted by the paper is that the UK needs more energy-efficient buildings to save energy but with the best benefit-cost ratio projects. The aim of the paper is to find the most inclusive and accurate calculation of cost-benefit analysis.

The paper was descriptive, illustrating the different cost-benefit analysis methods like performing scenario modeling after the sensitivity analysis and calculating the net present value. This paper describes the methods used in this study but does not conduct any analysis of EETAs. There are no results in this paper that could be used as a reference in this study. It is of the least relevance but its used methods were useful to this study.

2.5 Paper 4:

Application and Importance of Cost-Benefit Analysis to Energy Efficiency Projects in Public Buildings: The Case of Serbia (Mihic et al., 2012)

The paper is addressing the high electricity prices in Serbia issue. It aims at proving that choosing Energy Efficiency applications based on cost-benefit analysis would maximize the benefit of a project.

The analysis was done on a portfolio of public buildings (schools and hospitals). The functions of the buildings were chosen because of their high impact on the community and their attractiveness to investors (WTP-Willingness to Pay). In the CBA, the cost calculation included a fixed price, not a market price, and the interest on a loan was also added. The Benefit included direct economic benefits, environmental benefits, and social benefits.

The results showed 39% average savings from the EE project with some buildings reaching 50%. 42% to 50% of CO2 emissions were reduced and a thermal comfort survey made in schools (grading 1-5) showed an improvement of 1 grade (20%). The paper includes the social and environmental factors in its analysis, which was not done in this study. However, it doesn't mention the EETAs included in the study or their individual results. It only mentions the overall savings achieved by EETAs. Furthermore, the study was done in Serbia, which has different climatic conditions than Egypt.

2.6 Paper 5:

Possibilities of Application of Cost-Benefit Analysis to Energy Efficiency Projects in Buildings (Mihic et al., 2011)

In Serbia, there has been a significant loss of energy in buildings from high consumption. Energy Efficiency projects are needed to decrease the country's energy use. However, these projects need to be cost-effective as well, so the use of CBA is crucial for determining the best energy-efficiency application technology. The paper's aim is to give a guide on how CBAs are done or planned to be done in Serbian EE projects.

The paper categorizes the EE measures into three points: measures of the host energy management that includes users' behaviors, low-cost measures of energy efficiency (tech. that costs less than 1000 euros), and high-cost measures of energy efficiency (tech that costs higher than 1000 euros). It also discusses the reasons behind the implementation of EE projects, which include economic, high-quality comfort, technical reasons, environmental protection, and legal restrictions. The method of performing the CBA in this paper included understanding social, economic, and institutional context, project identification, feasibility analysis, financial analysis, socio-economic analysis, and risk assessment. The CBA was calculated using NPV, IRR, and payback period.

This paper's categorization of technology and economic evaluation tools used were beneficial for this study. There were no useful results to compare findings to but it served more as a guide for the process of economic evaluation of the energy-efficient technology in buildings.

2.7 Paper 6:

Energy efficiency in multi-family residential buildings in Latvia. Cost-benefit analysis comparing different business models (Zvaigznitis et al., 2015)

The literature mentioned problem is that residential buildings don't receive energy performance contracts (EPC) as much as the rest of the sectors. However, these contracts would benefit residents as they pay a lot for energy and renovation, so a guarantee of efficiency would help save their money. The aim of the research is to explore the benefit of an EPC on residential buildings.

The method used in the paper is a comparative analysis of the cost-benefit of three similar buildings: a building renovated with EPC, a building renovated with traditional ways, and an unrenovated building. The EETAs tested in this study were the building envelope and space heating renovation and the new domestic hot water system. The results showed that the EPC renovated building residents will pay the least (renovation plus energy cost) but will get their payback after 20 years. The traditionally renovated building residents will pay more but will get payback after 15 years, and the unrenovated building residents will pay the most and will have to buy another house in 15 years.

The above-mentioned paper's testing methodology was useful to this study, but it focused on retrofitting old buildings with EETAs. However, this study focuses on new buildings. Also, the paper didn't test all the EETAs used in this study and was conducted in Latvia which has mild and humid temperatures rather than hot and dry conditions like Egypt.

2.8 Paper 7:

Modeling Energy Efficiency Performance and Cost-Benefit Analysis Achieving Net-Zero Energy Building Design: Case Studies of Three Representative Offices in Thailand (Lohwanitchai and Jareemit, 2021)

Because in Thailand Zero Energy Buildings are high in cost with the unclear and inconsistent design approach, the paper aims to present a guide for cost-optimal zero-energy office buildings in Thailand. The researchers used a comparative analysis of 3 office buildings in Thailand with different sizes.

The study used eQuest as the energy simulation software and Dialux evo for daylight simulation. For the Cost Benefit Analysis, it used NPV, IRR, and payback period calculation. The used EETAs were Envelope (glazed windows and insulated walls), shading devices, light, cooling, and PV. The results showed that all EETA applied decreased the energy consumption greatly of the 3 buildings, however, no building reached net zero. The medium-sized building had the most savings in energy and most savings came from light and cooling EEAT.

This paper's methodology and results were useful to this study, but it didn't include all EETAs used in this study. Furthermore, the tested buildings were in Thailand which has tropical weather rather than Egypt's hot and dry climate.

None of the found papers were conducting analysis in Egypt. The papers used different methods of cost-benefit analysis, but all considered the economic factors in their analysis. Few of the above papers linked their findings with the economic factors in their country and offered potential scenarios. This show that there is a gap in the literature on the economic analysis of EETAs in Egypt and relating their NPVs' impact on current economic conditions. Therefore, this study aims to cover this gap and test EETAs in Egypt for their incremental cost and savings and highlight possible scenarios that could affect the cost-benefit of certain EETAs.

Chapter 3: Tools and Methodology

This study aims at finding ways to decrease the cost-benefit ratio of Energy Efficient Technology Applications (EETA) in office buildings. According to the background research, the building sector in Egypt (Residential and Commercial) consumes almost 65 percent of Egypt's total energy consumption. However, the available building data are mostly for commercial, office buildings; therefore, office typology is chosen to be the subject of this study.

To achieve this study objective, three energy simulation programs (EDGE, Build_Me, and eQuest), that are free and accessible to anyone, were chosen to calculate the energy savings of each EETA in three different building sizes. The EETAs that were tested in this study were based on their availability in the three chosen simulation software. The cost of each EETA is calculated as a sum of its market price, installation cost, and maintenance cost. The output data were then

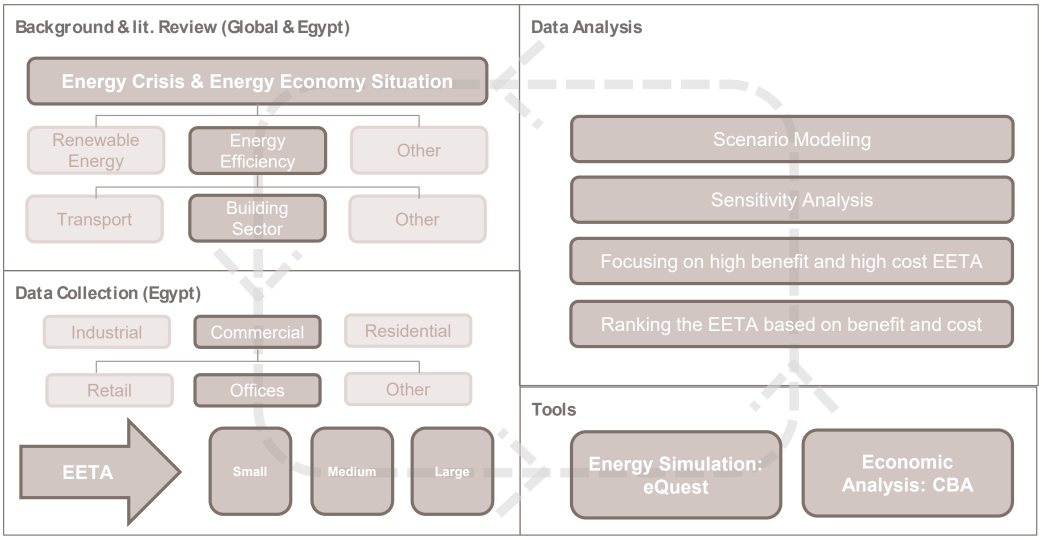


Figure 9: Methodology (by Author)

used to calculate the Net present value (NPV) of each EETA's cost-benefit, taking into consideration different discount rates. The EETAs were then ranked based on their NPV results to identify the worst and best EETA to invest in according to the building size.

Finally, the cost and savings of each EETA were graphed in a dot scatter graph to categorize the EETA into high savings-high cost, high savings-low cost, low savings-high cost, and low savings-low cost. Based on the NPV rankings and the categorizing of the EETA, the three EETAs that have high cost and savings, and low NPVs were chosen to perform a sensitivity analysis. After identifying the most impactful factors that would affect the cost and benefit of the EETA, scenario modeling would be conducted to identify the best-case scenario that would help decrease the cost-benefit ratio of the EETAs. (See Figure 9)

3.1 Energy Simulation Tools

3.11 EDGE:

Excellence in Design for Greater Efficiencies (EDGE) is a software, standard, and certification system that is developed by the International Finance Corporation (IFC), a member of the world bank. It promotes sustainable and resource-efficient construction practices and allows architects, engineers, and developers to assess the environmental impact of their building designs and identify strategies for reducing energy, water, and embodied energy use. The software could be accessed through its website: https://app.edgebuildings.com/

The software is designed to calculate the operational savings and cost impact of every technology application applied to the building. It includes different building typologies like homes, offices, light industry, hospitals, hotels, and retail. It contextualizes the base case according to the building's location. The cost calculation method used in the software is based on International Cost Conversion Tool, which estimates the total building cost based on its location. However, this cost is a rough estimate and can't be broken down into individual items (EDGE Cost Model, 2015). Therefore, the cost estimation feature of EDGE software is not used in this study.

EDGE's calculations are based on the building's design, specifications, type, occupant use, and climatic conditions of its location. It uses base case data that are customized based on each country's building performance codes. More customized base case data has been collected from country-based institutions for accurate measures. The base case systems efficiencies are based on ASHRAE 90.1 2007. (EDGE Methodology Version 2, 2019)

3.12 Build_Me (Building Energy Performance (BEP) tool)

Build_Me is a project that is supported by Guidehouse, The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, and The International Climate Initiative. The project mainly aims at accelerating the building sector with zero emissions in the MENA region. The project focuses on Egypt, Lebanon, and Jordan and is based on studies made in these countries. All studies were supported by national partners in these countries. In Egypt, the partners were the Integrated Development Group (a multidisciplinary engineering consultancy), the Housing and Building Research Center (a national agency connected to the Ministry of Housing of Egypt), the European Bank of Reconstruction and Development (EBRD), Regional Center for Renewable Energy and Energy Efficiency (RECREE) and Egypt Green Building Council.

Build_Me team has developed a Building Energy Performance (BEP) Tool to help buildings in the MENA region assess their buildings in comparison to local baselines. The BEP tool measures the energy performance of buildings

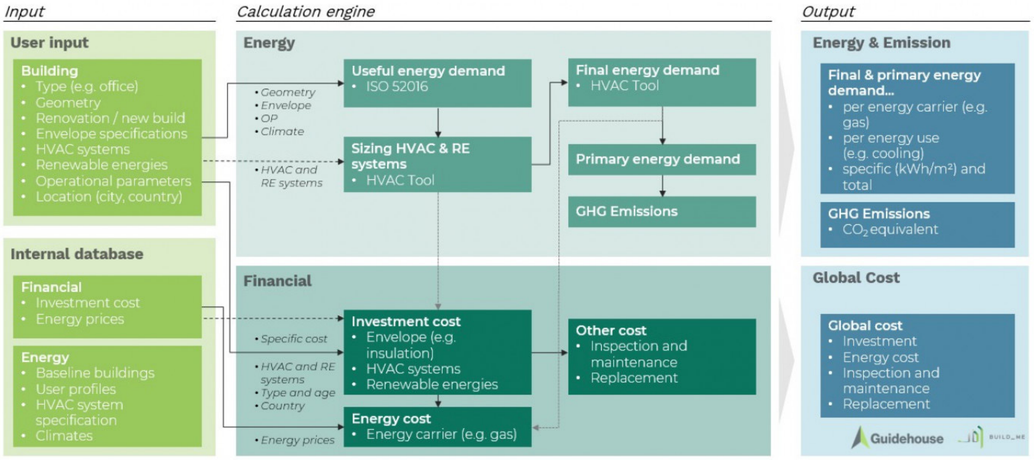


Figure 10: Calculation methodology of the Buildings Energy Performance Web App, indicating the necessary inputs and possible outcomes (Build_Me, 2022)

and the cost-effectiveness of their applied EETAs. The BEP tool methodology uses specific building data and BEP internal database (which has its data from country-based studies and data collection) as an input for the calculation engine (which is based on ISO 52016 for energy calculations) to have an output of energy and emissions and global cost. (See Figure 10). The tool could be accessed from the Build_Me website for free: https://www.buildings-mena.com/

The base case, which forms the BEP baseline, was developed in each country with the help of national entities. The baseline data was based on data from a minimum of 5 chosen case studies buildings in each typology, that are not older than 3 years, and data collected from subsidy programs, interviews, literature, permit documents..etc. (Guidehouse, 2022)

3.13 eQuest

eQuest is an energy simulation model developed by the US Department of Energy (DOE). It is intended to support energy consultants, architects, and engineers in assessing and enhancing building energy performance. To simulate and analyze the energy consumption, thermal comfort, and environmental impact of various building design options, the software integrates a thorough calculating approach.

When evaluating a building's energy use over a long period of time, eQuest employs a thorough, hour-by-hour simulation methodology. To produce precise projections of energy usage, it considers variables including the environment, occupancy patterns, building materials, HVAC systems, and lighting. The DOE-2 engine, which has a reputation for being accurate and dependable in energy modeling, serves as the foundation for the software's calculating approach. Additionally, eQuest supports several building energy codes and standards, enabling customers to determine whether they are in compliance with standards like ASHRAE 90.1, Title 24, and LEED. (Energy Design Resources)

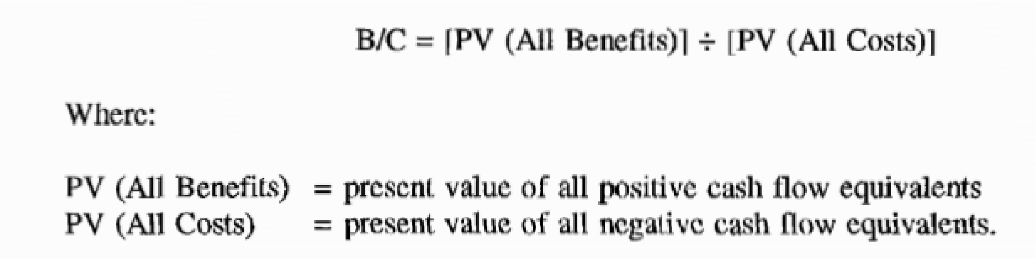
eQuest customizes the energy simulation based on the building's location and weather files inputted by the user. For the finances, eQuest assumes a KWh price and calculates the savings accordingly. However, the KWh price could be changed by the user for more accurate calculations. In this study, the eQuest software was used only for energy savings calculations without the actual financial calculations. The base case in eQuest is customized based on the building's input data which includes: the building's geometry, orientation, construction materials, HVAC systems, lighting fixtures, occupancy schedules, and other relevant parameters. The software then calculates the estimated energy consumption of the reference building.

3.2 Economic Analysis & Evaluation Tools

This study conducts an economic analysis for each EETA to evaluate and compare their economic benefits. There are many tools that are usually used to evaluate EETAs economically and that could have been useful for this study including Cost-Benefit Analysis (CBA), Cost-Effectiveness Analysis (CEA), and Cost-Utility Analysis (CUA).

CBA is a tool that uses monetary values of benefits and costs to evaluate a certain investment from an economic efficiency perspective. It entails identifying and assessing the direct and indirect costs, as well as the benefits, connected to a specific project or program. Direct spending includes investment costs, operations costs, and maintenance costs, whereas direct benefits include things like greater revenue, cost savings, or better health outcomes. The equation used to calculate the cost-benefit is shown in Figure 11.

Cost-effectiveness analysis (CEA) compares the costs of various interventions or policies with the corresponding results or benefits. It focuses on figuring out the most effective strategy to attain a particular result, like faster outcomes, less carbon emissions, or lower death rates. In this method the cost is calculated as the monetary value and the effect is not usually related to money but rather the impact of the evaluated technology. This tool is often used in healthcare because the benefit of, for example, saving a life is the targeted benefit rather than financial benefits.



$$B/C = [PV\ (\text{All Benefits})] \div [PV\ (\text{All Costs})]$$

Where:

PV (All Benefits) = present value of all positive cash flow equivalents
PV (All Costs) = present value of all negative cash flow equivalents.

Figure 11: Cost Benefit Analysis (Shor, Packey& Holt, 1995)

CUA includes the effects of energy efficiency technologies on human health, the environment, and society in addition to financial costs and benefits. A common utility metric, such as quality-adjusted life years (QALYs) or environmental impact indicators, is used to quantify the results. Decision-makers can compare and rank energy efficiency technologies according to their total societal value or impact through CUA.

In this study, the Cost-Benefit Analysis is used to assess the different EETAs because it compares financial inputs of cost to the benefit's financial gains. The monetary calculations are the most important aspect of this study as the EETA's are being compared based on their affordability and economic value. The results of this analysis are then used for the ranking of EETAs.

3.3 Data Interpretation

To further interpret the results of the analysis and link it to the overall socio-economic situation in Egypt, two tools were used in this study: sensitivity analysis and scenario modeling. Both tools are used in many studies for identifying impactful aspects and how will the results be affected by their change.

Sensitivity Analysis measures the effect of a factor or a number of factors on the output or results. These factors usually hold a notion of uncertainty. (Saltelli & Annoni, 2010) For example, the electricity price in Egypt changes frequently. This affects any Net Present Value (NPV) calculations because the future savings would drastically increase with the increase in electricity prices. In that sense, sensitivity analysis is used in this study to determine the uncertain factors that could affect the results of this study. That would help with the understanding of how the results could be altered positively or negatively and by which factors. This would also help in the next phase of the study, which is scenario modeling.

After the impactful factors are identified and tested, Scenario Modeling is used to determine the best- and worst-case scenario for each of the resulting EETA. Scenario Modeling is an examination of potential futures. Several assumptions are tested to predict possible risks that might occur. (Beebe, 2021) In this study, scenario modeling is used to predict how the current country's socio-economic situation and most impactful factors could affect the EETAs' benefit-cost ratio if changed in the future. This would help set recommendations for stakeholders and other researchers regarding the future of EETAs in Egypt.

Chapter 4: Hypothetical Case Studies and Baseline Setting

4.1 Hypothetical Case Study

Based on previous studies, the savings of each EETA differ based on the building size that this technology is installed in. Therefore, different building sizes were needed to properly assess the different EETAs' savings. However, there is no available database of office buildings and their sizes in Egypt. There are only data on buildings that register for green certifications in some cities in Egypt (like Cairo, Alexandria, Aswan…etc.), which is available on the websites of green buildings certifications in Egypt (LEED, EDGE, Tarsheed, and Green Pyramids Rating System). The buildings data available on these websites showed that there is a total of 105 buildings and 51 of those were office building typology.

Three data sets were extracted from the available data: there were 19 buildings that have areas bigger than 20,000 sq meters, 15 buildings with areas between 10,000 and 20,000 sq meters, and 17 buildings that have areas less than 10,000 sq meters. The office buildings have an average of 6-13 stories. The biggest building has an area of 500,000 sq meters and the smallest building registered has an area of 600 sq meters. From these buildings, 3 building sizes were calculated based on the average areas of the three data sets.

The Small Building has an area of 4,847.22 sq meters that is divided into 6 stories (5 above ground and 1 underground for parking). The building size ratio is 3:4, which makes the dimensions of the building 24.6 m x 32.85 m. The area of each floor is 808 sq meters. The floor-to-floor height of the building is set to be 3.5 meters, which is the average floor-to-floor height in the available office buildings' data.

The Medium Building area is calculated to be 13,235.35 sq meters. It has 8 stories in total, 7 of which are above ground and 1 underground. The building's aspect ratio is the same as the small building 3:4, so it has a width of 35.2 meters and a length of 47 meters. The floor-to-floor height is also set to be 3.5 meters and the area of each floor is 1,654.42 sq meters.

The Large Building has a calculated total area of 76,453.44 sq meters with dimensions of 66.4 meters and 88.57 meters. It has 13 stories with 2 stories underground and 11 above ground. The area of each floor is 5,881 sq meters. The floor-to-floor height is also 3.5 meters. All three buildings have long dimensions towards the North and South directions and the shorter side towards the West and East dimension, based on the common buildings' orientation in Egypt.

Each software requests certain data to be input for the building modeling and simulation. Where possible, all input data were the same. The buildings' Climate zone was inserted as 2B (hot and dry, Egypt's climate) in the three software. The three buildings were inserted as new construction that has a heating system that ran on electricity. It was also assumed that electricity is used to heat water in the three buildings.

	Small Building	**Medium Building**	**Large Building**
No. of Occupants	189	514	2,969
Open Plan Office area (m)	2,666.0	7,279.4	42,049.4
Private/Closed Office area (m)	484.7	1,323.5	7,645.3
Corridor area (m)	242.4	661.8	3,822.7
Conference area (m)	193.9	529.4	3,058.1
Data Center area (m)	48.5	132.4	764.5
Lobby area (m)	242.4	661.8	3,822.7
Kitchen & Food Preparation area (m)	193.9	529.4	3,058.1
Bathrooms area (m)	193.9	529.4	3,058.1
Indoor Car Parking area (m)	387.8	1,058.8	6,116.3
M&E Rooms, Store area (m)	193.9	529.4	3,058.1

Table 1: EDGE assumed area distribution and no. of occupancy. (by author)

EDGE assumed the number of occupants in each building and the area distribution of space based on their areas, as shown in Figure 12. This data was then used as input in eQuest. Build_Me BEP tool didn't require these inputs.

4.2 Energy Consumption

The baselines of each software were identified to set the reference values of each building size. EDGE calculated the baseline yearly energy consumption of the Small Building as 81.65 KWh/m2, the Medium Building 74.25 KWh/m2, and the Large Building 67.61 KWh/m2. According to EDGE, energy consumption is distributed among measures in different percentages, as shown in Figure 13. The equipment in EDGE contributes 34-41 percent of energy consumption in the base case. Lighting is the second energy-consuming measure with 20 percent. Cooling and Heating come third with an average of 16-18 percent.

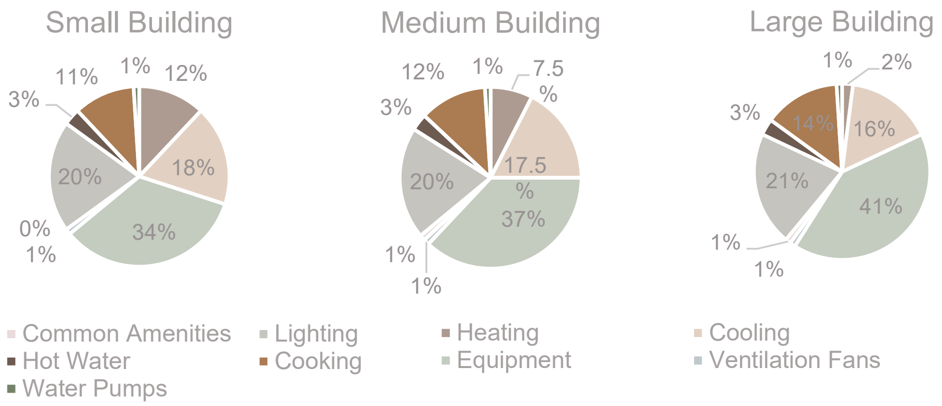


Figure 12 EDGE Baseline Energy Consumption (by author)

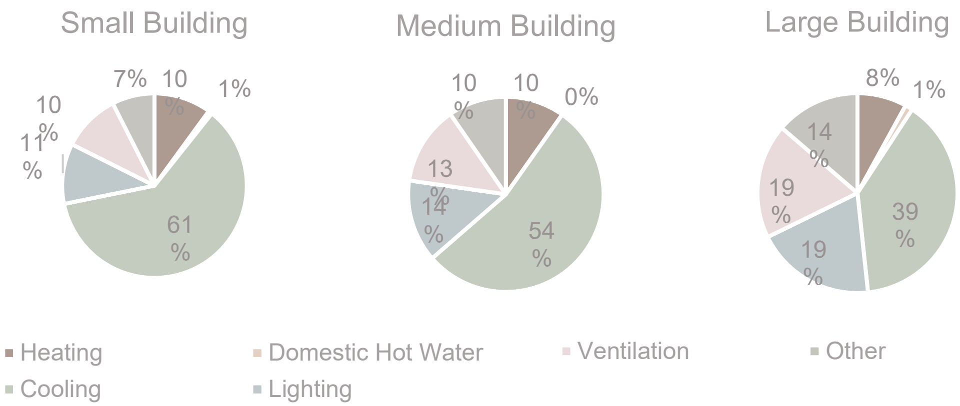


Figure 13 Build_Me BEP tool Base Case energy consumption (by author)

Build_Me Building Energy Performance (BEP) tool calculates the base case to consume 164.2 KWh/m2 in the Small Building, 126.61 KWh/m2 in the Medium Building, and 78.72 KWh/m2 in the Large Building. Build_Me data shows that cooling is the most energy consuming measure with an average consumption of 39-61 percent of the total buildings energy usage. The second most consuming measure according to Build_Me is Lighting, which is similar to EDGE data, with a consumption of 11-19 percent. The third is ventilation with 10-19 percent energy consumption.

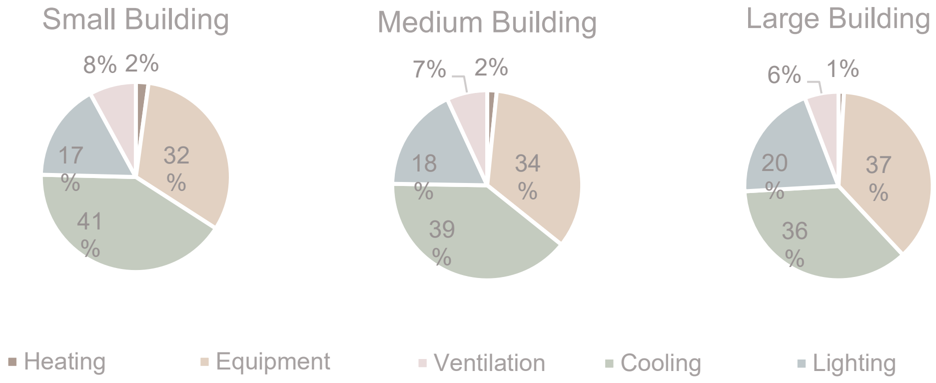


Figure 14: eQuest Base Case Energy Consumption. (by author)

eQuest Base case energy consumption is 119.54 KWh/m2 in the Small Building, 112.12 KWh/m2 in the Medium Building, and 101.9 KWh/m2 in the Large Building. Similar to Build_Me, eQuest base case has cooling as the most energy consuming measure with 36-41 percent; but, like EDGE, it also has equipment consuming a similar amount of energy 32-37 percent. Lighting also consumes a similar percentage as the other two software 17-20 percent, as shown in Figure 14.

The three software have different percentage distributions of energy, but they meet certain results. For example, the Lighting in all three software is almost 20%, which is similar to the results of most studies. However, EDGE and eQuest consider the equipment energy consumption to contribute to a huge percentage of the building consumption, while Build_Me doesn't consider it as a major energy use measure. Cooling was also considered the most energy-consuming measure in eQuest and Build_Me, but EDGE puts it in the second position after equipment. The difference in the calculations may be caused by the different data sourcing of each software. See Table 2. This study doesn't focus on the comparison between the three software and their accuracy; it rather uses these three software results averages to calculate the savings of each EETA. Further studies, on actual buildings as case studies, would be needed to identify which software reflects the real-life case in Office Buildings in Cairo, Egypt.

	EUI	EDGE	BUILD_ME	eQuest	EUI (EIA)*	EUI (UNEP)**
Small	Yearly Consumption (kWh/m2/year)	81.65	164.2	119.54	130	84
	Energy Cost ($/kWh)	0.052				
Medium	Yearly Consumption (kWh/m2/year)	74.25	126.61	112.12	159	
	Cost of Operation ($)	0.052				
Large	Yearly Consumption (kWh/m2/year)	67.61	78.72	101.90	183	
	Cost of Operation ($)	0.052				

* Energy Use Intensity calculated by EIA Commercial Buildings Energy Consumption Survey (CBECS) based on size and climate
** Energy Use Intensity calculated by UNEP based on location and type of building

Table 2: EUI of software and Electricity cost used in baselines (by author)

4.3 Energy Efficiency Technology Applications (EETAs) Included

There are many EETAs used in office buildings that could contribute to energy savings. Not every EETA is included in the three software used in this study. Table 3 shows the baseline technology applications used in each software and their values. The EETAs values were pre-set in all software as default values. Light bulbs and light controls exist in the three software with similar data for the base case. The Window Wall Ratio in all software was set to 40% and the Walls and Roofs colors were set to be medium absorbent color. For the Cooling system, the DX split units with COP 3 data were used as a baseline in all software. All software had no external shading on the base case, but Build_Me was considered an internal manual shading.

The measure with the most variant, nonetheless, is the U-Value of walls, roof, and window glass. For the walls and window glass u-value the variant between the 3 programs was small; as they have values that are near 2 W/m2.K for the wall U-Value and 3.2 W/m2.K for the window glass U-value. The roof U-value, on the other side, varies greatly. In Build_Me the base case roof U-value is 0.6 W/m2.K, while in EDGE it is 1.91 W/m2.K, and in eQuest 2.31 W/m2.K. The rest of the

EETAs were excluded in this study because they either didn't exist in all software or they have no alternative (better performance) option in all software. Smart meters and sub-meter measures exist only in EDGE and were not considered in Build_Me and eQuest. The Domestic Water Heater (DWH) had better performance options (like boiler, solar, or heat pump) in EDGE, but in Build_Me there was only an existing or doesn't exist option. In eQuest the DHW didn't have better performance options, there was only choosing between natural gas or electricity options. For the heater, the 3 software didn't have similar options to choose from.

		EDGE	Build_Me	eQuest
1	Light Bulbs	65 L/W	Linear fluorescent Lamps	0.64 W/ftsq
2	Light Controls	No Auto Controls	No Auto Controls	No Controls
3	WWR	40%	40%	40%
4	Roof SRI	45	Intermediate Color – 60	Medium abs. 0.6
5	Walls SRI	45	Intermediate Color - 60	Medium abs. 0.6
6	HVAC	Air Cooled DX Split System – COP: 2.78	Central System – COP: 3	DX Coils
7	Shading	No Shading – AASF 0.12	Manual Shading	No shading
8	Wall Insulation	U-Value: 1.86 W/m2.K	2.1 W/m2.K	2.11 W/m2.K – 8 in
9	Roof Insulation	U-Value: 1.91 W/m2.K	0.6 W/m2.K	2.31 W/m2.K – 8 in
10	Windows	U-Value: 3.5 W/m2.K	3 W/m2.K	3.21 W/m2.K
11	Domestic Hot Water	100% Boiler	Exist – NA	Natural Gas
12	Meters	No Smart Meters	NA	NA
13	Sub-meters for cooling	No sub-meters for cooling	NA	NA
14	Heating	Electric Resistance	AC Heater	Electric Resistance

Table 3: EETAs Base case inputs. (by author)

So, this study focuses mainly on the 10 EETAs with available data in the three software: Light bulbs, Light Controls, Window Wall Ratio (WWR), Roof Solar Reflectivity Index, Walls Solar Reflectivity Index, Cooling systems, External Shading, Wall Insulation, Roof Insulation, and Windows Glass U-Value. For each EETA 3 alternatives were used for better savings.

For the light bulbs, Compact Fluorescent Light (CFL) bulbs and Light-Emitting Diode (LED) bulbs were used as alternatives that consume less energy than regular Fluorescent light bulbs. The LED bulbs were used twice with different efficiencies. The CFL bulbs have an efficacy of 70 L/W, LED bulbs type 1 have an efficacy of 100 L/W and LED bulbs type 2 have an efficacy of 150 L/W. The light controls available in the Egyptian market and used in this study for simulation were automatic on/off controls based on motion sensors, continuous dimmer, and timer control with continuous dimmer.

The Window Wall Ratio (WWR) was decreased from the base case (40%) by 5 percent three times; the first case was a building with 35 percent WWR, the second with 30 percent WWR, and the third with 25% WWR. The Solar Reflectivity Index (SRI) of both the roof and the walls was improved from the medium absorbent base case to 3 cases: painting the walls or tiling the roofs with white color (SRI=85), medium grey color (SRI=65), or medium beige color (SRI=55). These values were picked based on the general colors used in buildings' facades in Egypt.

Three dimensions of external shading were used to simulate the effect of overhangs and fins on the building's energy savings. The overhangs were put on the northern and southern elevations because based on the sun pathway in Egypt, the sunlight is usually coming from above these directions. The eastern and western elevations usually get most of the sunlight from the sides because the sun pathway in Egypt is tilted towards the south. The first length was 0.5 meters of overhangs on the Northern and Southern elevation windows and 0.5 meters of fins on the Eastern and Western elevation windows. Similarly, the second and third chosen overhangs and fins lengths are 1 meter and 1.5 meters.

The insulation (U-Value) of both the walls and roofs were set on fixed 3 values that were less than most of the base cases' values. The U-values used in the walls and roof insulation were 0.46, 1, and 1.45 W/m2.K. These values also resemble different roof and wall insulation sections. The design of the roof and wall sections were not particularly studied in this research, but the resulting U-values were more focused on. The window glass alternatives were also set using U-values rather than the window glass section design. The U-values used for more efficient window glass in the simulation are 3.35, 2.9, and 2.45 W/m2.K.

Finally, the cooling systems chosen in this study as better alternatives for the DX split system were chosen based on their availability in the three software used in this study for energy simulation. The first type used is Air Cooled Chiller with COP 3, the second type used is Variable Refrigerant Flow (VRF) air cooled with COP 4, and the third type used is Water Cooled Chiller with COP 5.

4.4 Cost

For the base case cost calculation of EETAs, the market price was used. The cost calculations included the capital cost of the technology, the installation cost, and the maintenance cost. The cost of electricity was fixed at $0.052 per kWh to be used in the savings and consumption monetary calculations. Table 4 shows the cost calculation of each technology for the base case assumptions based on market prices. The cost that is used in the benefit-cost analysis of the EETAs is the incremental cost, which is the cost of the EETAs deducted from the base case technology cost.

Cost of Baseline					Small Buildings		Medium Buildings		Large Buildings	
EETA		Unit Price egp	Unit Price $	Unit	Qty	Total	Qty	Total	Qty	Total
Bulbs	Flourescent Lamps 65 L/W	60.00	$2.00	Bulb	932	$1,864.32	2,545	$5,090.52	14,703	$29,405.17
WWR	40%	3,000.00	$ 100	Window	608	$60,828.00	838	$83,844	1,299	$129,876
Roof SRI	45	300.00	$10.00	m2	808	$8,080.00	1,654	$16,544	5,881	$58,810.00
Walls SRI	45	15.00	$ 0.5	m2	1,824.84	$912.42	2,515.32	$1,258	3,896.28	$1,948.14
External Shading	No shading	-	$ -	window	0	$0.00	0	$0	0	$0.00
Roof Insulation	U-Value: 1.91	120.00	$4.00	m2	808	$3,232.00	1,654	$6,618	5,881	$23,524.00
Wall Insulation	U-Value: 1.86	120.00	$4.00	m2	1,824.84	$7,299.36	2,515.32	$10,061	3,896.28	$15,585.12
HVAC	Air Cooled DX Split System – COP: 2.78	1,500,000.00	$ 50,000	unit	1	$50,000.00	2	$100,000	3	$150,000
Windows	U-Value: 3.5	3,900.00	$130	Window	608	$79,076.40	838	$108,997	1,299	$168,838.80

Table 4: Cost of Base line technology. (By Author)

Chapter 5: Data Analysis: Simulation and Economical Evaluation

Using the EDGE, Build_Me, and eQuest, each of the selected 30 EETAs was run to determine their savings in each building size (Small, Medium, and Large). The resulting savings percentages were then multiplied by the base case electricity consumption of each software and the cost of electricity to convert it to money savings. The incremental cost of each EETA was also calculated using market price, by deducting the cost of each EETA from the cost of the replaced base case technology. The savings and the incremental cost are graphed to determine the high cost – high savings EETA, high cost – low savings EETA, low cost – high savings EETA, and low cost - low savings EETA. In addition, the monetary values of the cost and savings of each EETA are used to calculate the Net Present value (NPV).

5.1 Savings

Each EETA was inserted into the three different software programs independent from the other EETAs to measure its effected savings on the base case. Figures 15-17 show the results of each EETA savings in each software and building size (Exact savings could be found in Appendix A). The Compact Fluorescent Light (CFL) bulbs resulted in a small saving percentage (0.35-1.85 %) in all software. The three software also showed that the effect of the CFL bulbs savings increase slightly when the building size increases. LED light bulbs with an Efficacy of 100 L/W have significant savings from the base case (4.43 – 8.15 %). The LED light bulbs' savings are around 5 times more than the CFL bulbs' savings. The savings also increase when the building size increases.

The third EETA in the light bulb measure, LED light bulbs with an efficacy of 150 L/W, was available in EDGE and eQuest but wasn't available as an option in Build_Me. However, the results of EDGE and eQuest showed that LED light bulbs with an efficacy of 150 L/W save 9.89-11.42% from the base case energy consumption. The savings of this EETA type also increases as the building size increases. It saves energy 9 times more than the CFL and 1.3 times the other LED light bulb type with less efficacy.

The light controls results showed some discrepancies between eQuest and the other two software. EDGE showed that the auto on/off light control saves (1.86-3.02%), the continuous dimming saves (2.62-3.79%) and the timer control with continuous dimming saves (2.75-4.09%), with the highest saving in the Large Building. Similarly, Build_Me results show savings of (2.1-3.88%) in both the auto on/off and continuous dimming and (4.21-7.76%) in the timer control with continuous dimmer, with the biggest savings in the Large Building. eQuest didn't have the timer control with a continuous dimmer option and the other light control options show the most savings in the Small building and the least in the large building (2.13-6.49%).

Opposed to the previous EETAs, the Window to Wall Ratio (WWR) decrease produced the most savings in Small buildings and the least in Large buildings. This might be caused because as the building increase in dimension, the effect of heat transfer from windows on the overall internal temperature decreases. The 35% WWR saves 0.01-2.22%, the 30% WWR saves 0.04-4.46%, and the 25% WWR saves 0.04-6.76%.

For the roof and elevation colors, Build_Me has one option better than the baseline (light color), so only the Solar Reflectivity Index (SRI) of 85 was considered in the simulation in the Build_Me BEP tool. The SRI of the roof's savings, based on results from EDGE and Build_Me, decreases as the building size increases, which makes sense as the effect of the roof heat absorption would affect less building area as the stories (building height) increase. However, eQuest shows the opposite results; with savings ranging (from 0.71-2.4%), eQuest shows that as the building size increases the roof SRI value increase resulting in more savings.

Overall, all the software shows that the most saving occurs from having a white roof (SRI=85), then a light grey roof (SRI=65), and at the end a light beige roof (SRI=55). Same as the roof results, the SRI of the walls, based on eQuest and Build_Me, decreases as the building size increases (results range:

0.38-3.7%). Only EDGE shows that the savings from an improved elevation walls SRI increases when the building size increases (results range: 0.06-0.27%).

The results of the shading simulation were very different in each software. EDGE showed that the shading overhangs and fins only result in savings with a depth of 0.5 meters. Even then, the savings are minimal (0.05-0.1%). EDGE shows that the depths of 1 and 1.5 meters overhangs and fins produce a negative effect on the energy savings of the buildings base cases in buildings sizes Small and Medium (results range: - 0.19 to – 0.01%). For the Large buildings, EDGE shows that the shade depths of 1 and 1.5 meters will result in 0.19% and 0.21% energy savings. Build_Me only had the option of having a fixed shade which results in negative savings in all buildings sizes (results range: -1.48 to -5.26). eQuest, however, shows positive results that decrease when the building size increases. The resulting savings in eQuest also increase as the depth of shade increases (results range: 1.07-4.6%).

Roof and Wall insulations in all software save energy the most in Small buildings. The roof and wall insulations with different thicknesses result in savings that increase with the decrease of the U-Value. The roof insulation savings on EDGE of all U-values in different building sizes ranged between 0.13% to 2.82%, and the savings range is 0.87% to 1.57% in eQuest. Build_Me BEP tool shows negative results with the U-Values of 1.45 and 1 (Results Range: -5.11% to -2%) but shows savings with a range of 0.67% to 1% with U-Value 0.46 insulation.

The external wall insulation showed savings in all software in all building sizes. The savings of the wall insulation decreases as the building size increases. In EDGE the savings of the wall insulation with different U-values range between 0.1% to 5.17%. Build_Me showed a higher savings range, between 1.17% to 10.92%. eQuest showed savings similar to EDGE's results, with a savings range of 0.52% to 1.35%. Window glass U-Value savings, according to EDGE and Build_Me, decreases as the building size increases, like the wall insulation (Results Range: 0.12% - 2.08%). On eQuest the window glass type with all tested U-Values showed negative results (Results Range: - 5% to -2%).

The cooling systems chosen for the study varied greatly in their savings. In EDGE, the air-cooled chiller with COP 3 has savings of 1.6% and 1.19% in the Small and Medium Buildings respectively, and the Large building has a negative result (-2.36%). The same cooling system in the Build_Me BEP tool has savings of 3.5%

and 1.29% in the Small and Medium Buildings and also a negative result in the Large building (-0.36%). The Air-cooled chiller in eQuest resulted in 8.23%, 7.9%, and 7.21% savings in the Small, Medium, and Large Buildings respectively. The second system tested, Variable Refrigerant Flow (VRF) air cooled with COP 4, has savings on EDGE of 6.31%, 5.07%, and 2.28% in the Small, Medium, and Large buildings. The Build_Me showed significantly higher savings than EDGE; the Build_Me savings were 27.64%, 28.76%, and 21.19% for the buildings from Small to Large.

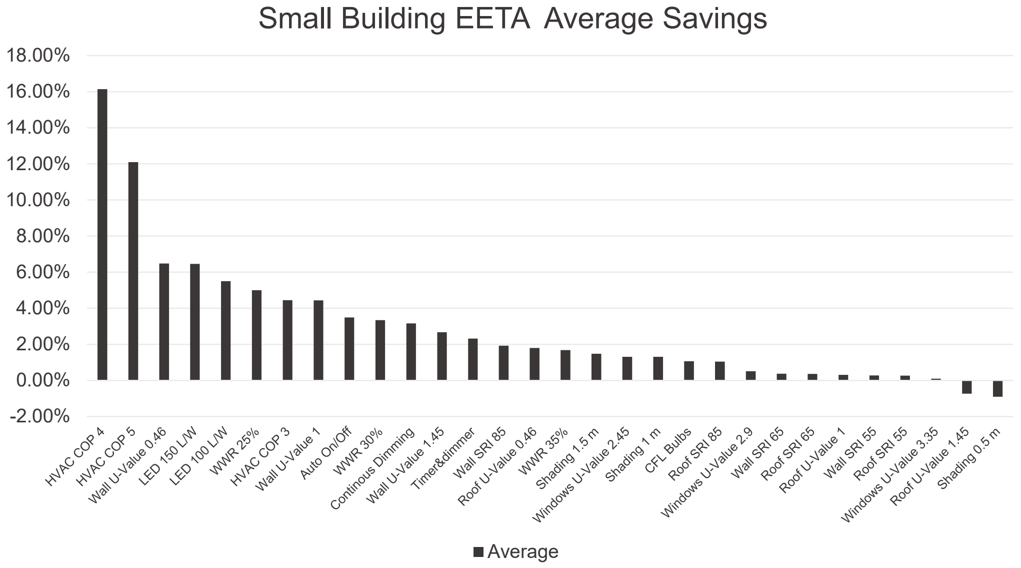


Figure 15: Average Savings small building (by Author)

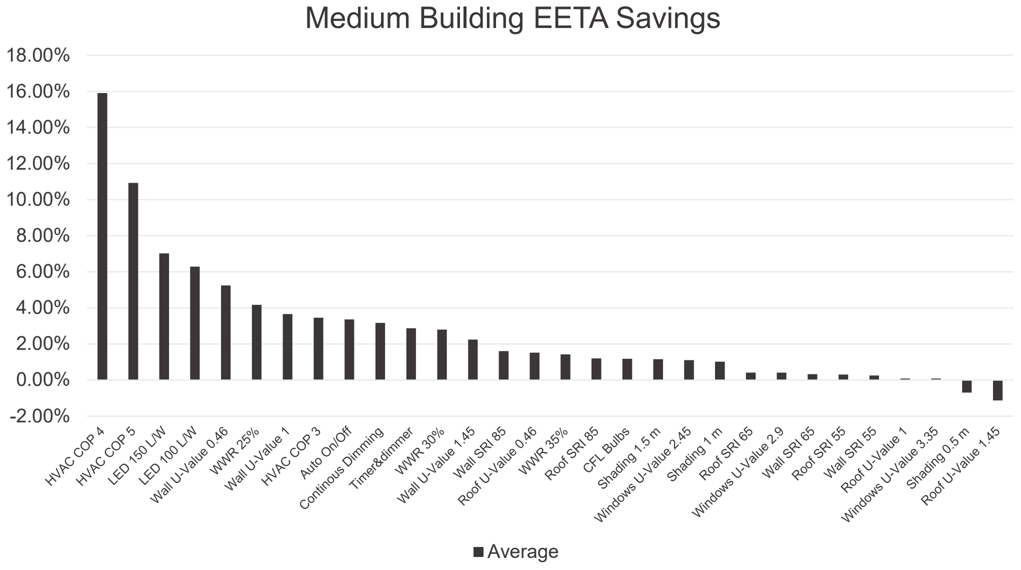


Figure 16: Average savings of Medium Building (by Author)

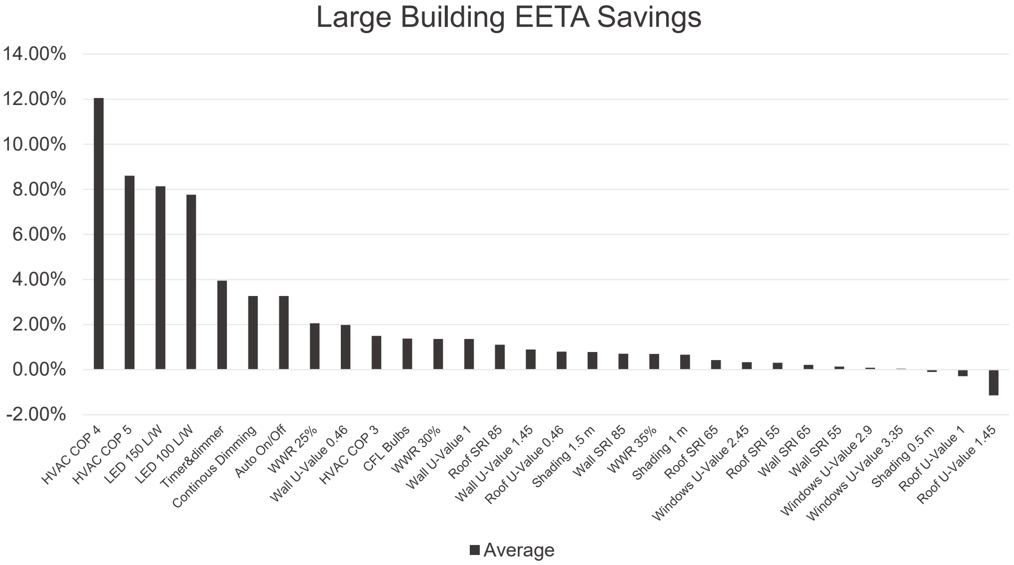


Figure 17: Average savings in Large Building (by Author)

eQuest showed savings that are less than Build_Me and higher than EDGE; the resulting savings from eQuest were 14.48%, 13.89%, and 12.69% for the buildings from small to large. The third system tested is the Water Cooled Chiller with COP 5. Savings on EDGE ranged from 2.26% to 4.43% with the largest savings in the Small building. Build_Me savings for the third system ranged from 7.52% to 13.72% and eQuest savings ranged from 16.04% to 18.14%. All the software showed the most savings in the cooling system appeared in the Small sized building and the least in the medium-sized building.

5.2 Cost

After calculating the savings using energy simulation software, the cost of each EETA was calculated using the EETAs' market price. The cost of the EETAs was then deducted from the cost of the base case technology. The incremental cost was then used in this study to identify the benefit-cost ratio of each EETA. The unit cost of each technology and EETA was multiplied by the quantity that is estimated according to each building size. Some results were negative because the EETA implementation would save from the initial cost of the building and some incremental costs were zero because the EETA had the same price as the regular base case item. (Appendix B contains the incremental cost data).

Compact Fluorescent Light (CFL) bulbs are 20% more expensive than regular fluorescent lamps but the buildings would require fewer CFL bulbs because they have a better luminous efficacy. So, the incremental cost of CFL is $299.62 in the small building, $818.12 in the medium building, and $4,725.83 in the large building. LED light bulbs with luminous efficacy of 100 L/W costs the same as CFL bulbs and LED bulbs with luminous efficacy of 150 L/W cost 17% more than CFL bulbs; however, fewer LED bulbs are required in a building than CFL and fluorescent bulbs. As a result, both types of LED bulbs have negative incremental cost; the LED bulbs with an efficacy of 100 L/W has incremental costs - $349.56, - $954.47, and - $5,513.47 in buildings from small to large, and the LED bulbs with efficacy 150 L/W has incremental costs of - $652.51, -$1,781, and -$10,291.81 in buildings from small to large.

The light controls in the base case of the three software are non-existent. Therefore, the incremental cost of the light controls is the actual cost of each technology. This made the cost of the light controls significantly higher. The cost of the auto on/off controllers was $3,462.3 in the small building, $9,453.81 in the medium building, and $54,609.6 in the large building. The continuous dimming controllers cost $2,423.61 in the small building, $6,617.67 in the medium building, and $38,226.72 in the large building. The timer control with continuous dimming costs $4,039.35 in the small building, $11,029.45 in the medium building, and $63,711.2 in the large building.

The Window to wall ratio reduction is different from the rest of the measures because there is no added technology. There is a decrease in the number of installed windows in the elevations, therefore the cost of the building is reduced. The 35% WWR resulted in a negative incremental cost of -$7,603.5 in the small building, -$10,480.5 in the medium building, and -$16,234.5 in the large building. Similarly, the WWR of 30% and 25% calculated negative costs are -$15,207 and -$22,810.5 in the small building, -$20,961 and -$31,441.5 in the medium building, and -$32,469 and -$48,703.5 in the large building.

The Solar Reflectivity Index (SRI) of the roof and elevations required only changing the color of the roof tiling and the external wall paint; thus, there is no incremental cost needed for the color change of these two elements. The window shades, on the other hand, are very expensive, considering the base case contained no external shading elements. The 0.5 meters overhangs and fins would cost $26,612.25, $36,681.75, and $56,820.75 in the small, medium, and large buildings. The 1-meter overhangs and fins would cost $45,621, $62,883, and $97,407 in the small, medium, and large buildings. The 1.5-meter shades would cost $57,026.25, $78,603.75, and $121,758.75 in the buildings from small to large respectively.

The cost of the roof insulations with the chosen U-values was deducted from the base case insulation with U-Value 1.91 W/m2.K. The resulting incremental costs for the roof insulation with U-Value 1.45 are $1,616 in the small building, $3,308.84 in the medium building, and $11,762 in the large building. Roof insulation with U-value 1 has added costs of $4,848, $9.926.51, and $35,286 in small, medium, and large buildings. The incremental cost of the roof insulation with a U-value of 0.46 is $8,888 in the small building, $18,198.59 in the medium building, and $64,691 in the large building. Wall insulation incremental cost was calculated in the same method as the roof insulation.

That resulted in incremental costs of $3,649.68, $5,030.64, and $7,792.56 for the wall insulation with a U-value of 1.45 W/m2.K in buildings from small to large. Insulation with U-value 1 W/m2.K has added costs of $10,949.04 in the small building, $15,091.92 in the medium building, and $7,792.56 in the large building. Also, the incremental costs of the U-value 0.46 W/m2.K wall insulation are $20,073.24, $27,668.52, and $42,859.08 in the buildings from small to large.

The window glass U-value costs were deducted from the base case window glass U-value, which is 3.5 W/m2.K. The cost of the window glass with U-value 3.35 W/m2.K is $12,165.6, $16,768.8, and $25,975.2 for buildings from small to large. Almost double the cost of the first glass U-value, is the glass U-value of 2.9 W/m2.K, with incremental costs of $42,579.6, $58,690.8, and $90,913.2 for buildings from small to large. The window glass with U-value 2.45 has incremental costs of $103,407.6, $142,534.8, and $220,789.2 for small, medium, and large buildings.

The most expensive technology was the cooling system. The base case is an air-cooled DX split system with COP 2.78. The air-cooled chiller with COP 3 has additional costs of $200,000 in the small building, $650,000 in the medium building, and $1,350,000 in the large building. For the Variable Refrigerant Flow (VRF) system with COP 4, the incremental costs are $450,000 in the small building, $1,400,000 in the medium building, and $2,850,000 in the large building. The water-cooled chiller will cost an additional $250,000 in the small building, $1,100,000 in the medium building, and $4,350,000 in the large building.

5.3 Cost Benefit Analysis using Net Present Value

The cost-benefit of each EETA in this study was determined by calculating their Net Present Value (NPV). There are four discount rates used in the NPV equation for each EETA which were based on the common interest rates of the Environmental Protection Agency (ETA), which are 3%, 7%, and 10%, and the interest rate of current Egyptian Central bank, which is 16%. The 16% is a high-interest rate, but it is the current rate in Egypt due to inflation.

This rate could change in the future and that is going to affect the economic evaluation of the EETAs. Since there were six savings results for each EETA in each building size and program, the NPV of all six savings results was calculated using the four discount rates. The NPVs were calculated using the NPV equation in Excel. Then the average NPVs of all the software were used to determine the EETA ranking in terms of profitability as an investment. (Appendix C shows the NPV calculations)

For the small building, the NPVs calculated with the 3% discount rate showed that the best EETA to invest in is decreasing the Window to Wall Ratio (NPV: $17,692, $35,305, & $52,877). This is mostly because when the windows are decreased, money and energy are saved. The second and third EETAs with a high NPV result are the external wall insulation (NPV: $17,440, $24,096, $31,085) and the light bulbs (NPV: $2,476, $20,506, & $24,315). These two EETAs have relatively close results. The fourth EETA with high NPV is light controls (NPV: $4,463, $9,157, & $9,304).

The fifth is the high Solar Reflectivity Index in roofs and external walls (Roof SRI NPV: $2,054, $2,817, & $8,189 and Walls SRI NPV: $725, $960, & $5,028). The rest of the EETAs have very low or negative NPVs. Roof insulation has NPV results of -$7,435, -$2,452, and $5,304). The windows U-value and shading NPV results were -$95,525, -$39,541, & -$11,584, and -$48,121, -$37,799, & -$32,088, respectively. The lowest NPV results are for the cooling systems (NPV: -$407,725, -$194,751, & -$183,716).

The rest of the rates (7%, 10%, & 16%) had a similar order of EETA NPV results with small differences. The 7% discount rate calculated NPV results showed that the second EETA with high NPV was the energy-efficient light bulbs rather than the wall insulation, which came third in the EETA order. In the 10% discount rate calculated NPV results the wall insulation came fourth in the ranking of EETAs after WWR, Light bulbs, and light controls. Similarly, in the 16% discount rate calculated NPV results the wall insulation is lowered a rank.

It came fifth after WWR, light bulbs, light controls, and SRI. Except for the wall insulation, all the other EETAs maintained their NPV results rank. The EETAs with negative values, however, kept increasing with the increase of the interest rate. So, the 16% discount rate NPV results showed five EETAs with negative NPV values (Cooling system, Window glass U-value, Shading devices, wall insulation, and roof insulation).

The medium-building NPV results were similar to the small-building results. The wall insulation U-value rank kept changing when the discount rate increased. For example, the 3% discount rate calculated NPV showed that the highest values came from the Window to Wall Ratio (NPV: $30,512, $60,367, and $90,175), then the Wall insulation (NPV: $36,414, $52,524, and $61,983). Like the small building 3% discount rate calculated NPV results, the light bulbs came third (NPV: $6,409, $54,841, and $61,983) and the light control came fourth (NPV: $13,600, $19,318, and $20,526).

The order of the rest of the EETAs was Roof & walls SRI, Window glass U-value, window shade, and cooling systems (in the order written). The rest of the NPV results that used different discount rates (7%, 10%, and 16%) showed the same EETA order, except for the wall insulation that showed third in the 7% and the 10% discount rate results and fourth in the 16% discount rate results.

The Large building has a different EETA ranking from the small and medium buildings' ranking. The EETA with the highest NPV in the large building is the light bulbs. In the NPV results that were calculated with a 3% discount rate (d.r.), the light bulbs had NPVs of $33,904, $310,250, and $329,951. The EETA that came in second place was the Window to Wall Ratio (3% d.r. NPV: $61,153, $120,157, and $181,524). The third EETA is the Wall insulation with 3% d.r. NPV of $67,818, $91,449, and $125,008. The light controls and the roof/walls SRI come fourth and fifth in the EETA order with 3% d.r. NPVs.

The lowest NPVs were for the roof U-value, window shade, window U-value, and the cooling system (in the mentioned order). The NPV results that were calculated with discount rates of 7%, 10%, and 16% showed similar EETA rankings. However, like the small and medium buildings, the wall insulation kept decreasing in rank as the discount rate increased. In the 7% & 10% discount rate calculated NPV results the wall insulation ranked fourth and ranked fifth in the 16% discount rate calculated NPV results.

The three building sizes showed similar rankings of the EETA according to their NPVs, however, there were some differences in the ranking of a few EETAs. All building sizes had the Roof insulation, Window glass U-value, Windows shade, and cooling systems as the EETAs with the worst four NPVs. The medium and small buildings have a Window to wall ratio with the best NPV results, but in

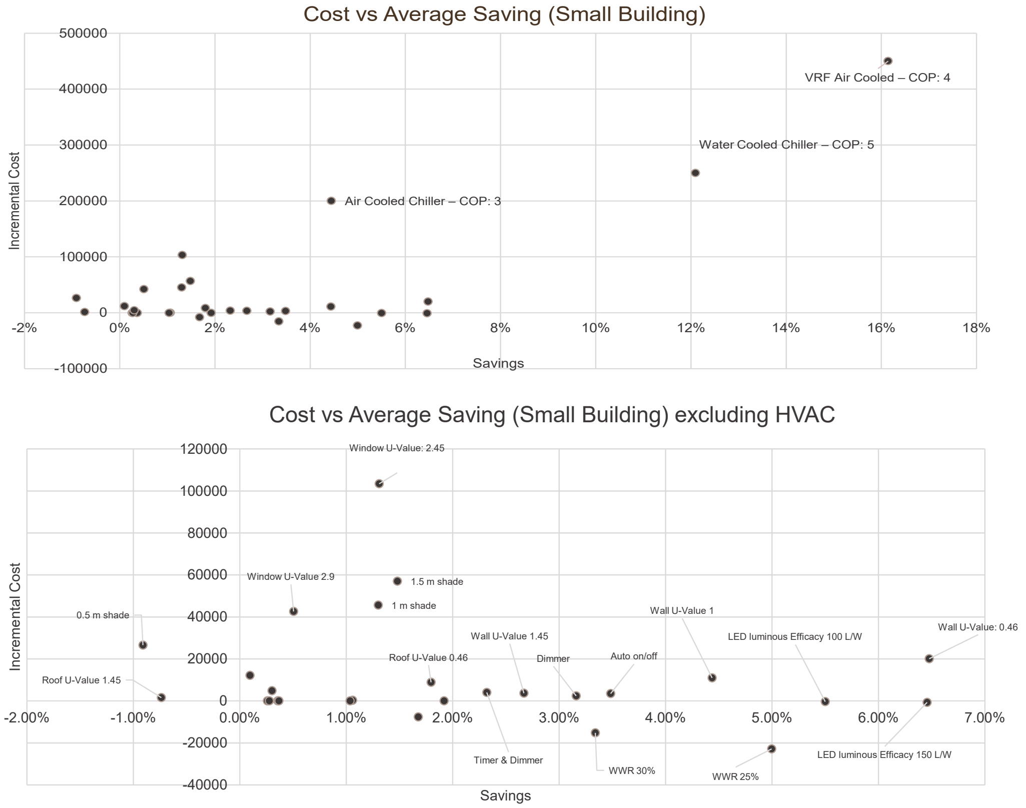
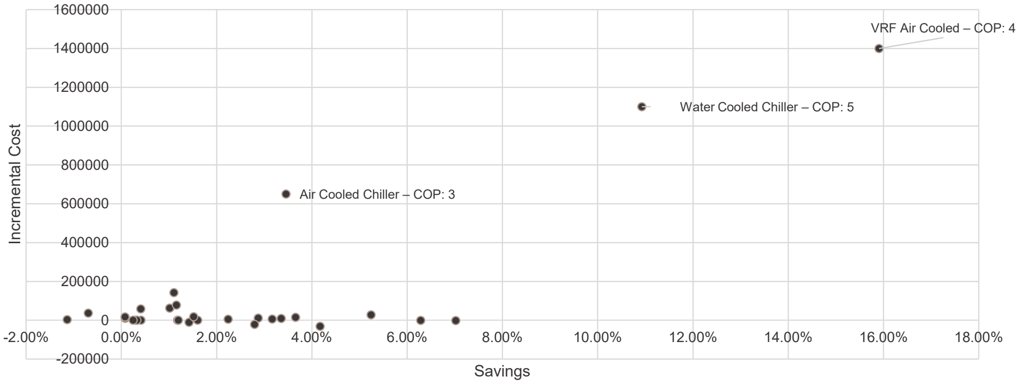


Figure 18: Incremental Cost vs Average savings with and without cooling systems – Small Buildings (by Author)

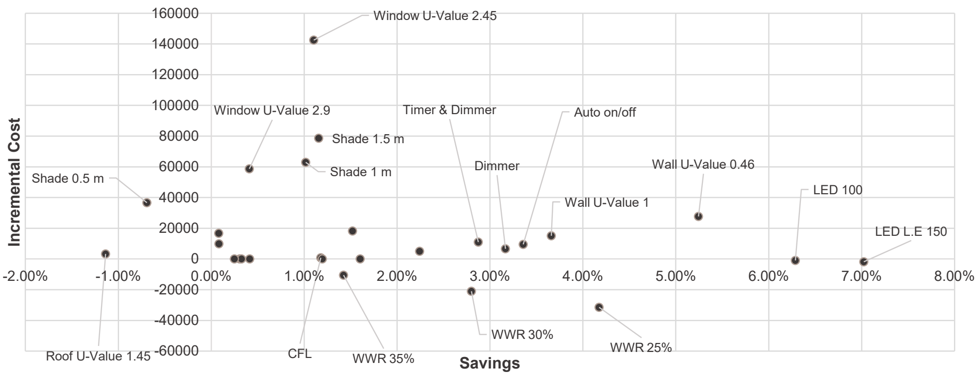
the large building, the light bulbs were the EETA with the best NPV results. The second place in the EETA ranking changed to each building's size. In the small building, the second-ranked EETA was the light bulbs, the medium building has the wall insulation as the second-ranked EETA, and the large building has the window-to-wall ratio as the second-ranked EETA.

5.4 Incremental Cost and Savings

The EETAs were also sorted based on their incremental cost versus their savings to determine the high-cost-high savings EETAs that would need to be further studied for improvement. The below graphs were first made with all the EETAs, but then the graphs were re-made with the cooling systems excluded as their costs and savings varied largely from other EETAs' costs and savings.



Cost vs Average Saving (Medium Building)



Cost vs Average Saving (Medium Building) excluding HVAC

Figure 19: Incremental Cost vs Average savings with and without cooling systems - Medium Building (by Author)

The small building cost-savings graph showed that the cooling system is the EETA with the highest cost and highest savings (figure 18). The cooling system that had the highest cost, but the highest savings is the VRF air cooled with COP 4 (Savings: 16.14% and incremental cost: $450,000). The water-cooled chiller with COP 5 has lower cost and savings than the VRF system and the air-cooled chiller with COP 3 has the least cost and savings of the cooling systems in the small building. The cooling system results were much higher than the rest of the EETA.

Thus, another graph was needed without the cooling systems. In the second graph (figure 18) the Wall insulation has high cost and savings than the rest of the EETAs. The EETAs with the low cost-high savings are the energy-efficient light bulbs, Window Wall Ratio, and light controls. The Window Glass

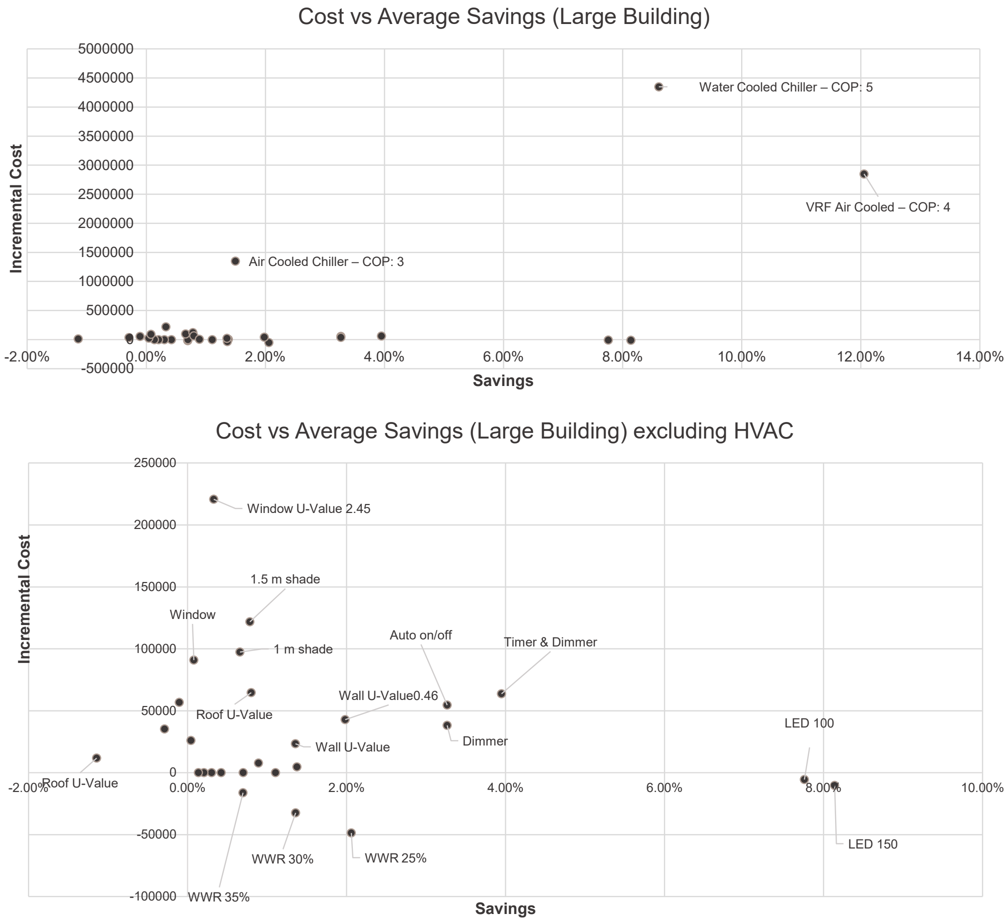


Figure 20: Incremental Cost vs Average savings with and without cooling systems - Large Building (by Author)

U-value and the windows' external shade are high cost-low savings EETAs. The SRI of the walls and roof and the roof insulation are low cost-low savings.

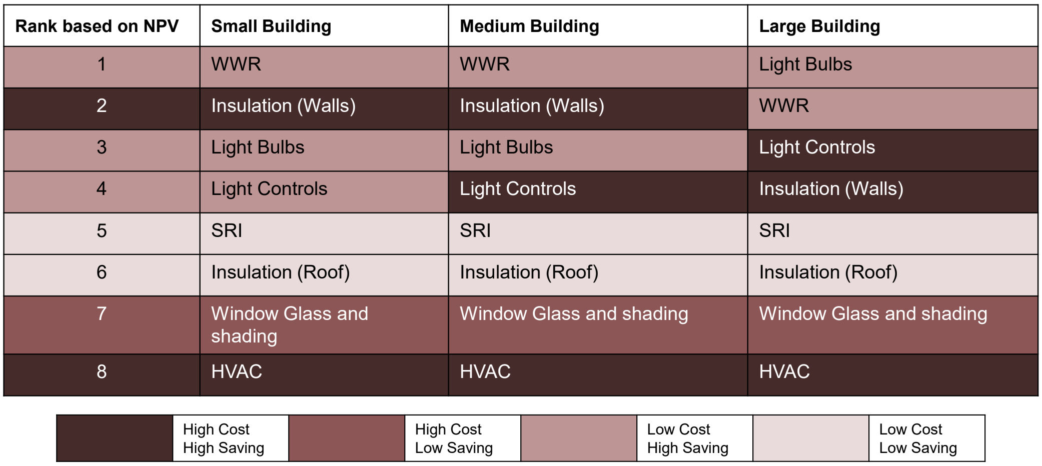
The graphing of the medium building incremental costs and average savings of EETAs showed similar results as the small building. The cooling system in the medium building has relatively much higher incremental costs and average savings than the rest of the EETAs. Like the small buildings results, the cooling system with the highest cost and saving is the VRF system with COP 4 (Cost: $1,400,000 and Savings: 15.91%). The water-cooled chillers with COP 5 come next and the air-cooled chiller with COP 3 comes last in the high cost and saving comparison of the cooling systems in the medium building. Figure 19 shows that the wall insulation and the light controls have relatively high-cost high savings, while the light bulbs and the Window Wall Ratio have low-cost high savings. The Windows glass U-Value and the Windows external shade have high cost-low savings. The EETAs with the lowest cost-low savings are the roof and wall SRI and the roof insulation.

The cooling system is again the highest cost and energy-saving EETA in the large building. However, in the large building, the VRF system has the most savings but not the highest cost (cost: $2,850,000 and savings: 12.05%). The water-cooled chiller has the highest cost but the second high savings (cost: $4,350,000 and savings: 8.61%). The air-cooled chiller has the lowest savings and costs from the cooling systems (Cost: $1,350,000 and savings: 1.5%). The EETAs with high cost-high savings in the large building, after the cooling system, are the light controls and the wall insulation like the medium building. Similar to the small and medium buildings, the EETAs with the high cost-low savings are the window glass U-value and the external window shade. Also, the light bulbs and the Window Wall Ratio have low-cost-high savings results. The wall and roof SRI and the roof insulation in the large building are EETAs with low cost-low savings category.

5.5 EETAs to study further

The Net Present Value calculations of the three buildings showed that the cooling systems are the EETA with the lowest values in all building sizes. The cooling systems also have the highest cost and savings EETA in the three building sizes. This makes the cooling systems the best EETA to study further for a potential benefits cost improvement opportunity. The three cooling systems could be further studied regarding their suitability with the building size. For example, the results showed that the VRF system is the best system to be used in large buildings because they become cheaper than water-cooled chillers and achieve better savings.

The second lowest NPV results were for the window glass U-Value and the external window shade. However, these two EETAs have high cost-low savings results, which makes them not qualified for further study. That is because they wouldn't affect the buildings' savings much, even if they were provided with lower costs. Therefore, these two EETAs will not be studied further in this study. The next EETAs with low NPV results in the three buildings are the roof insulation and the walls and roof SRI. These three EETAs cost very little and save relatively little energy in all building sizes. They would be worth studying further for more efficiency, but there is little to improve regarding their cost and savings. Thus, the walls and roof SRI and the roof insulation would not be studied further in this research



Rank based on NPV	Small Building	Medium Building	Large Building
1	WWR	WWR	Light Bulbs
2	Insulation (Walls)	Insulation (Walls)	WWR
3	Light Bulbs	Light Bulbs	Light Controls
4	Light Controls	Light Controls	Insulation (Walls)
5	SRI	SRI	SRI
6	Insulation (Roof)	Insulation (Roof)	Insulation (Roof)
7	Window Glass and shading	Window Glass and shading	Window Glass and shading
8	HVAC	HVAC	HVAC

■	High Cost High Saving	▦	High Cost Low Saving	▤	Low Cost High Saving	□	Low Cost Low Saving

Figure 21: EETAs Heatmap based on results (by Author)

.

The EETAs with the highest NPV results were Window Wall Ratio reduction and energy-efficient light bulbs. These two EETAs have very low costs but cause very high savings. This makes them the most recommended EETAs to be used in any building aiming for energy efficiency. Because they are already low-cost-high savings EETAs, there is little room for improvement. So, they will not be studied in more detail in this study. Light controls and wall insulation have high Net Present Value results in all building sizes and are sorted as high cost-high savings EETAs in medium and large buildings. This makes light control and wall insulation EETAs that could be further studied to improve their cost-benefit ratio. To sum up, the EETAs that are going to be discussed further in this study are the cooling systems, the wall insulation, and the light controls. See Figure 21.

Chapter 6: Based on the analysis: Finding Opportunities for Cost Reduction and Benefit Increase

In the last chapters, ten EETAs were analyzed for their performance in three building sizes using three different software to identify the EETAs that have the potential for cost-benefit optimization. Based on the analysis done three EETAs were chosen to further study opportunities of cost reduction and benefit increase. The three EETAs are the cooling systems, wall insulation, and light controls.

6.1 Cooling Systems

The first EETA to be further examined for its potential for improvement is the cooling system. In this study only three air conditioning types were tested: air-cooled chiller with COP 3, Variant Refrigerant Flow (VRF) air-cooled with COP 4, and water-cooled chiller with COP 5. The cooling sector situation in Egypt and the impactful factors on the cooling systems are two aspects that are important to understand to determine potential advancements.

6.11 Cooling Systems in Egypt

Egypt has very high temperatures due to its proximity to the equator. Climate change has contributed to the rise of Egypt’s temperatures in past years, and it is expected to worsen even more in the future. This results in high demand for cooling systems, which in turn affects Egypt’s energy demands during summer highly. “During the peak summer months, 50 percent of the electric power goes to air conditioning,” said Alaa Olama, UNEP consultant. (UNEP, 2022).

The air conditioning systems in Egypt are very expensive and are not affordable for many. The high price of cooling systems in Egypt is mainly because they are not locally manufactured. The cooling systems are usually assembled in Egypt but the parts are imported from different countries (mainly India, China, and Malaysia). (Hassan et al., 2022) This makes the cooling systems' prices easily affected by inflation or new customs regulations and pricing.

Egypt has been putting priority on mitigating the impacts of the cooling sector on energy consumption and GHG emissions. In its Nationally Determined Contributions, Egypt has identified the cost of $250 million for key mitigation projects in the energy efficiency cooling in buildings. (Egypt NDC, 2022) The Energy Efficient Cooling in Buildings project aims to replace inefficient air conditioning systems in buildings with energy-efficient cooling systems. The project plans to achieve its objectives by offering a lending facility, in which end users could lend money with a 5% interest rate and 5-10 years repayment periods, to replace their old inefficient air conditioning. Figure 22 shows the stakeholder diagram of this project. The project is planned to be completed in the years 2022-2035. (NCC, 2022)

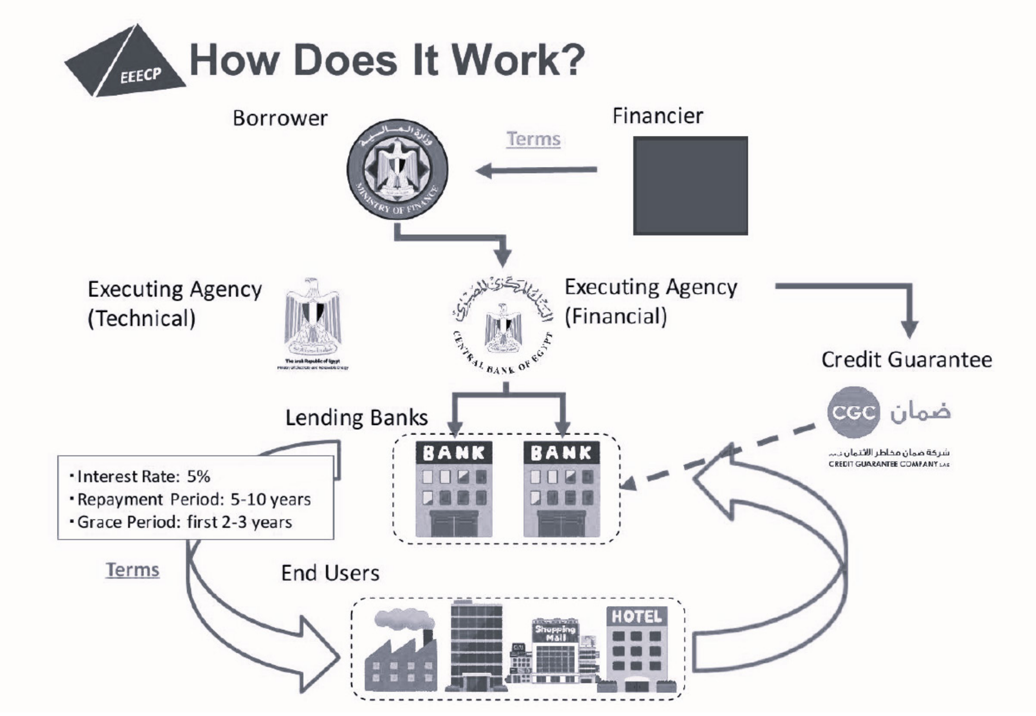


Figure 22: Stakeholder mapping of the Energy Efficient Cooling in Building project (NCC, 2022)

The project also considers three main risks and offers mitigation plans for them. The first risk is the inflation and price change, which would be mitigated by having international entities support guarantees and start manufacturing the cooling systems' parts in Egypt. The second risk is the disposal of old air conditioning systems in an improper way. The mitigation for that risk would be ensuring the proper disposal of the old ACs according to the international guidelines for AC disposal. The third risk is the lack of awareness of the users, which would be mitigated by forming awareness campaigns.

6.12 Important factors

Based on the analysis done on the cooling systems in this study and the research done on the cooling system situation in Egypt, there have been several impactful factors identified that would directly affect the cooling systems' cost and benefits. The first major impact factor that affects the cooling systems' cost is the fact that their parts are imported. This situation creates two factors that affect the cooling systems price directly; the first factor is the inflation and the second is the customs tariff. Any imported goods face an increase in prices when inflation occurs because of the difference in currency. The customs tariff in Egypt increases usually with inflation and regularly every couple of years.

The other factor that affects the cooling systems' cost is the high-interest rates that banks put on due to inflation. These high-interest rates make the cooling system a less profitable investment. Users would most probably put their money in the banks rather than replace their inefficient AC with an efficient one. The cost of electricity in Egypt is also another factor that directly affects the cost-benefit of the cooling systems. That is because the higher the cost of electricity the higher the monetary value of the cooling system's savings. This increases the benefit of the cooling system, thus making it a better investment option for users.

Some indirectly impactful factors would include the user's awareness. As the awareness of people increases of the energy efficiency benefits, the non-monetary benefits of the cooling system would increase. This wouldn't affect the cost-benefit much but would increase the sales of efficient cooling systems. End-users' unwillingness to pay much now to save more later affects the sales of efficient cooling systems because of their high capital cost. In addition, the rebound effect might indirectly affect the cost-benefit of the cooling systems. The rebound effect happens when users increase the use of their efficient cooling systems because of their knowledge that the systems don't consume much electricity. This rebound effect impacts the savings of the cooling system and makes it a bad investment.

6.13 Sensitivity Analysis

Inflation/customs tariff – capital cost increase:

In the sensitivity analysis, it is assumed that the inflation continues, and the prices of the cooling system would increase by 10% in one case and 20% in another. There is no assumption of a decrease in price because this rarely happens. In the first case, the NPV of the cooling system would be decreased by 11-13%. The second case would decrease the NPV of the cooling system by 22-26%. These results show that the inflation factor is highly impactful to the cooling systems' cost benefit.

Interest Rate:

In this factor the current discount rate of 16% would be tested if it increases by 5% and decreased by 5%; assuming the inflation might either increase or decrease in the future. The decrease of the discount rate by 5% resulted in an increase of the NPV by 1-3% and the increase of the discount rate by 5% resulted in a decrease of 1-2% in the NPV. This shows that the change in interest rate is moderately impactful.

Cost of electricity:

The cost of electricity would affect the monetary value of the cooling system savings. The NPV would be tested by assuming an increase in electricity prices of 10% and 20%. A decrease in electricity prices is not tested because it is unlikely to occur. The result of increasing the savings by 10% is a 1-3% increase in the NPV and the result of increasing savings by 20% is a 1-6% increase in the NPV. This shows that the cost of electricity is moderately impactful on the NPV of the cooling systems.

6.14 Scenario Modeling

Two factors, the capital cost, and the cost of electricity, are used to create four scenarios. Scenario one (best case scenario) assumes that the capital cost stays the same or decreases due to local manufacturers evolving and the subsidy is removed from the price of electricity, so the cost of electricity is higher. In that scenario, the cooling systems would cost the same or less, but their savings impact would be high due to the increased cost of electricity. This would make the energy-efficient cooling system a profitable investment rather than a luxury costly option.

Scenario two would assume a rise in capital costs and the cost of electricity. In this scenario, the energy-efficient cooling system would be expensive and would need further economic analysis to determine its feasibility even with the increased cost of electricity. The main reason for that is that capital cost is a more impactful factor on the EETA NPV than the cost of electricity, therefore, when both factors increase the savings would rarely cover for the increase in capital.

Scenario three assumes that the capital cost stays the same or decreases while the cost of electricity stays the same. This scenario is near to the current situation of energy-efficient cooling systems. In this scenario, the future would be the same as today, which would not be a good situation for the energy-efficient cooling system. That is because the capital cost of the cooling systems is very high that the NPV results are all negative in the three buildings and while using all the different discount rates.

Scenario four (worst case scenario) assumes that the cost of electricity stays the same and that the capital cost increases. In this scenario, the energy-efficient cooling systems would become unaffordable to many users and would in turn not be purchased. This could lead to users buying and reusing old inefficient air conditioners, which would not solve any of our energy consumption issues.

6.2 Wall Insulation

The wall insulation types in this study are chosen based on the U-value, not the insulation material as there are many insulation materials that could give similar U-Values. The U-values could also be achieved by increasing the wall thickness. The cost, however, was calculated assuming the insulation material was a mix between wall thickness increase and the installation of polystyrene. The chosen U-values that were tested are 1.45 W/m2.K, 1 W/m2.K, and 0.46 W/m2.K.

6.21 Wall Insulation in Egypt

Wall Insulation in Egypt is mainly imported. It is not widespread practice that a building would use wall insulation because it is considered expensive in Egypt. Commercial buildings, however, have wall insulation installed more than residential buildings in Egypt. In ancient times people used to depend on proper insulation for cooling. Thick walls were used before to avoid heat loss/gain and maintain the interior space cool in summer and warm in winter. However, with the spread of fans and HVAC, fewer and fewer buildings use wall insulation nowadays in Egypt. No note efforts are being made by the Egyptian Government to regulate wall insulation like the energy-efficient cooling system.

6.22 Impactful factors

Since most of the insulation raw materials are imported, the capital cost of the insulation is also threatened to fluctuate based on the inflation status and the customs tariff. However, it depends on the insulation type. Polystyrene is produced in Egypt, but the raw materials are imported. The discount rate is also an effective factor in the cost-benefit of wall insulation. The increase in the interest rate would result in a decrease in the benefit since it will make putting the money in the bank a better option than investing in wall insulation.

Like the cooling system, the price of electricity would also be an impactful factor in the benefit of the wall insulation. With the cost of electricity increasing, the benefits of wall insulation also increase. Other impactful factors include the lifetime of the wall insulation, but most wall insulation lives till the end life of the building, so this factor would stay constant. Another factor could be the transportation and cost of installation. This would depend on the location of the building and its proximity to the supplier’s warehouses and the cost of labor.

6.23 Sensitivity Analysis

Inflation/customs tariff – capital cost increase:

An assumption was made with the increase of the insulation premium pricing by 10% and 20%. The results varied greatly based on the discount rate used and the size of the building. For example, in the small building using a 3% discount rate, the NPV was decreased by 2-6%, using a 7% discount rate the NPV was decreased by 5-14%, using a 10% discount rate the NPV was decreased 8-45%, and using 16% discount rate the NPV was decreased 25-45%. This shows that the change in the capital cost of the wall insulation would impact its NPV greatly as the interest rates increase. The 20% cost increase showed an NPV decrease of 4-13% using a 3% discount rate, 10-54% using a 7% discount rate, 16-86% using a discount rate of 10%, and 48-90% using a discount rate of 16%. This shows that the cost of wall insulation is moderately impactful on its NPV.

Interest Rate:

The interest rate of 16% was tested to increase by 5% or decrease by 5%. The results of the NPV after decreasing the discount rate by 5% was an increase in the NPV results by 27-150%, which is a huge change percentage. The increase in the discount rate by 5% decreased the resulting NPV by 61-83%. The results show that the discount rate has a very high impact on the NPV of the wall insulation.

Cost of electricity:

The cost of electricity was assumed to increase by 10% and 20%. The results for the 10% increase in electricity prices show an increase in the NPV that used a 3% discount rate by 12-16%, that used a 7% discount rate by 15-37%, that used a 10% discount rate by 18-53% and that used 16% discount rate by 26-35%. This also shows that the cost of electricity impacts the wall insulation NPV highly.

6.24 Scenario Modeling

The scenarios would be made using the most impactful factors of the wall insulation which are the interest rate change and the cost of electricity increase. The first scenario (best case scenario) would assume that the interest rate is decreased, and the cost of electricity is increased. In this scenario, the cost-benefit of the wall insulation would vary greatly, as the value of the investment in wall insulation would increase along with its savings monetary value. This would make wall insulation a favorable EETA as it would save a lot in comparison to its initial cost.

The second scenario is when the cost of electricity stays the same, but the interest rate decreases in banks. This would increase the value of investing in wall insulation but would not affect the savings monetary value much. This scenario does not necessarily encourage developers to consider wall insulation in their buildings as the initial cost would still stay the same and the savings will also stay the same. This would, however, help investors in considering loan options, which in return would increase their capital limit. This might convince a developer to invest in wall insulation since there are better interest rates on loans.

The third scenario considers unchanged interest rates and an increase in electricity prices. This scenario would help convince developers who operate or use their buildings to invest in wall insulation because it will help them save on their electricity bills. However, developers that lease their buildings wouldn’t care much about the electricity bill as it would be paid by their tenants. They could still increase the unit price on the basis of the electricity savings.

The fourth scenario (worst case scenario) assumes that the electricity prices kept unchanged, and the interest rates kept increasing. This scenario might discourage any developer from investing in wall insulation because the electricity prices are not high enough to put money into the insulation instead of putting it in the bank or some other investing opportunity. The percentage of buildings that has wall insulation would not change except if other measures are taken like increasing awareness or producing the insulation raw materials locally.

6.3 Light Controls

The light controls used in this study are auto-on/off motion sensors, dimmers, and timer control with dimmers. These technologies help increase the energy savings of the building but have high costs. As the building size increases the light controls become more expensive and less feasible to have. Thus, further study is needed to try to improve their cost-benefit.

6.31 Light Controls in Egypt

Light controls in Egypt are mainly imported. They come from different countries with different qualities. They typically have a lifetime of 15 years. In general, Egypt is putting much effort into decreasing light consumption in the streets and public buildings through the installation of more efficient light bulbs, but there is no mention of light control use. There are no major national initiatives promoting the use of light controls in Egypt.

6.32 Impactful factors

Like the cooling system and the wall insulation, the inflation and the customs tariff would impact the light controls cost as they are imported, not locally manufactured. This would cause a direct increase in light controls capital cost when the custom tariffs increase or inflation occurs again. This situation also puts the risk of availability because when inflation occurs some imported goods are limited by the government to avoid loss of foreign currency. The other directly impactful factor is the current banks' interest rate. The increase in interest rates makes taking a loan a hard decision to make and limits investments to projects with high-profit margins. The light controls wouldn't generate profit but would help save on the cost of the operations. Other impactful impacts would include a lifetime of the light control device and the regular maintenance of the technology.

6.33 Sensitivity Analysis

Inflation/customs tariff – capital cost increase:

Similar to the two previously studied EETAs, the light controls NPVs were tested with an increase of 10% and 20% in cost. The 10% increase in the cost of the light controls decreased the NPV results, which use the different discount rates, by 3-29%. The 20% increase in the EETA cost caused the NPV results to decrease by 5-33%. This shows the high impact of the change in cost on the cost-benefit of the light controls.

Interest Rate:

The interest rate of 16% was changed to 11% one time and 21% the other to test the impact of the interest rate change on the light controls. The 11% interest rate resulted in a 52-69% increase in the NPV. The 21% interest rate has resulted in a 35-46% decrease in the light controls NPV. The impact of the interest rate on the cost-benefit of the light controls is very high.

Cost of electricity:

The cost of electricity was assumed to increase by 10% and 20% to test its impact on the light control NPV. The 10% increase in the cost of electricity resulted in a 14-39% increase in the NPV. The 20% increase in the cost of electricity caused the NPV to increase by 25-79%. This factor has a very high impact on the cost-benefit of the light controls.

Lifetime:

The average lifetime of the light controls is 15 years, however, some light controls if well maintained could live up to 25 years. The change in a lifetime would be assessed to determine its impact on the light controls NPV. The first assumption would be that the EETA would have a lifetime of 20 years and 25 years. The 20 years resulted in a 31-47% increase in the NPV results and the 25 years resulted in a 63-87% increase in NPV results. This shows that the lifetime of the EETA has a very high impact on its cost benefit.

6.34 Scenario Modeling

The two factors that are going to be used in the scenarios' formation are the cost of electricity and the interest rate fluctuation. The first scenario (best case) assumes that the interest rate is lowered, and the cost of electricity is increased. This scenario would make the choice of investing in light controls easier. The lowered interest rate would increase the benefit-cost of the light controls and would make the EETA a better investment option. The rise in electricity prices would also make light controls much needed for higher energy conservation.

In the second scenario, the cost of electricity would increase but the interest rate would not change or increase. This would make the choice of having a light control technology a very hard choice because although it will help in the saving of electricity consumption, its high premium cost could make its NPV negative value.

In the third scenario, the interest rate decreases but the cost of electricity stays the same. This scenario would help the light controls technology have a better NPV. The current cost of electricity makes the EETA NPV a positive value so the stagnation in the cost of electricity would not affect the EETA NPV negatively.

The fourth scenario (worst case scenario) assumes that the interest rate would stay the same or increase and the cost of electricity would stay the same. This scenario would make the light controls a bad investment and would not encourage developers to install the light control technology in their buildings. Other mitigation solutions could be taken by the government by adding the EETAs in the building codes and regulations to ensure energy savings. Also, local manufacturing of light controls would help decrease the EETA's capital cost and would decrease its impact from inflation and customs tariffs.

Chapter 7: Conclusion and Recommendations

7.1 Conclusion

This study aims to find opportunities to improve the benefit-cost of Energy Efficiency Technology Applications (EETA) in office buildings. The world is currently facing an energy crisis that is caused mainly by the Russian-Ukrainian war. Egypt is not affected much by this crisis as it has a surplus of electricity, mostly from oil and natural gas. However, Egypt has set targets to have 42% of its electricity sourced from renewable energy sources by 2035. This goal is ambitious since renewable energy is only 6% of Egypt's energy mix.

This goal needs not only the building of renewable energy plants with huge capacities but also decreasing our consumption of energy by using energy more efficiently. Since the building sector consumes a large percentage of Egypt's energy consumption, this study focused mainly on the building sector's energy efficiency. The available building data that could resemble Egyptian buildings with their areas and story height is the database of registered and certified green buildings in Egypt. Almost 50% of the buildings that exist in the database have office typology.

The case studies in this study are three hypothetical buildings of different sizes (Small, Medium, and Large) that were set based on the average building sizes in the green building database. The study uses three software programs with different baselines to assess the different EETAs that exist in Egypt. The software programs used are EDGE, Build_Me Building Energy Performance tool, and eQuest. EDGE is a building simulation tool developed by IFC to simulate building performance in developing countries.

Build_Me Building Energy Performance tool also assesses performance in buildings that exist in the MENA region against local baselines. eQuest is an energy simulation software that customizes its outputs based on the weather data and the buildings' input. The baseline data of the three software and their methodologies were studied and mentioned in this study. The available EETAs were then assessed based on their availability on the software and Egypt in general. Ten EETAs were then identified to be the focus of this research.

The EETAs were simulated using the three software programs to get the savings in each of the building sizes. The average savings were then calculated from the three software outputs. The cost of the EETAs was calculated based on their market price. Then the cost and savings were used to calculate the Net Present Value of each EETA using four discount rates (3%, 7%, 10%, and 16%). The savings and incremental cost of each EETA were graphed to sort the technologies based on their high/low cost and high/low savings.

Three EETAs were then chosen that have high cost high savings results to perform sensitivity analysis and scenario modeling on. The three EETAs with high-cost high savings results were the cooling systems, the wall insulation, and the light controls. The three EETAs had capital cost, interest rate, and cost of electricity as highly impactful factors that affects their NPV results. The light controls also had the lifetime as an additional highly impactful factor.

7.2 Recommendations

The outputs of the study showed that EETAs with low-cost, high savings would be most suitable to apply in buildings with low budgets but aiming to conserve electricity. These EETAs are energy-efficient light bulbs, especially LED with an efficacy of 150 L/W and the reduced Window Wall Ratio. These two EETAs were low-cost, high-savings in all building sizes. They also had high NPV results, which shows that they are economically viable. Light Controls in small building sizes are low-cost, high-saving EETAs that become of high cost when applied to large buildings. Further study is needed to determine the reason for this affordability change of the light controls based on the building size.

Window glass U-value and window shades have been found to be of high cost and low savings in all building sizes. This might be because the base case of this study had a 40% Window Wall Ratio (WWR). These two EETAs could result in more savings in buildings with higher WWR. Further studies are needed to determine the reason for their non-functionality. According to this study's results, however, the windows low U-value and external shades are not worth investing in if the building in the subject has a WWR of 40%. The roof and walls solar reflectivity Index (SRI) and the roof insulation in all buildings have low cost and low savings, which makes them good and cheap solutions to achieve further savings on a new building.

The high-cost high-saving EETAs (cooling systems, wall insulation, and light control) are mostly either completely imported or have components that are imported. This fact contributes to their high initial cost and could be mitigated by the government's support for local manufacturing of these technologies. Also, reducing customs on these EETAs would help make them more affordable. On the other hand, the subsidy that exists on the price of electricity needs to be removed or phased out so the users would begin using and investing in EETAs. As long as the electricity is cheap, the end users and developers wouldn't care much for savings. Only when the cost of electricity is high, the developers and end users would begin searching for energy-efficient solutions.

The inflation that caused high-interest rates makes investment in anything not a rational decision. One solution might be offering low-interest loans for buying energy-efficient technologies. Finally, the social aspect of EETA usage should be studied in further studies because of its impact on the adoption of EETAs in office buildings.

7.21 Stakeholders Roles

Different stakeholders have important roles in increasing the benefit-cost of EETAs. This study identifies the main reasons of the EETAs high cost are the importing of the technology or its parts/raw materials and inflation, while the low benefits of EETAs are mainly affected by high interest rates and low cost of electricity. The Egyptian Government, developers, financial institutes, and users could greatly contribute to the decrease in EETA premium cost and increase of their benefits.

Egyptian Government:

The Egyptian Government has the most vital role in the improvement of the EETAs' benefit-cost ratio. It could help motivate developers and citizens to adopt energy efficiency measures by providing incentives. The incentives could include low-interest loans on EETAs, tax credits, and grants. In addition, it could help spread public awareness and build capacities to help inform people about the urgent need for energy efficiency and conservation. This could be done by updating the schools' curriculum to include more knowledge on energy efficiency and performing awareness campaigns in offices, hospitals, public areas…etc.

Moreover, the government needs to form new energy policies and building codes to mandate using energy efficiency methods and technology. Thresholds on energy consumption per building type should be considered in the building codes to control unnecessary energy consumption. In parallel, the government could support local manufacturers to produce energy efficiency technology fully in Egypt without importing any element. This could be done through Public Private Partnership (PPP) projects, where the country and the private sector work hand in hand for the success of the project. In that regard, a plan should be included in the country's strategy for enhancing local manufacturing and depending less on imports.

The government should also consider reducing or phasing out the subsidy on electricity sooner. As long as the cost of electricity is low, the users would keep their energy consumption high. Instead, the government could offer subsidies on energy efficiency technologies, design, and solutions to lower the EETAs' initial cost and improve their cost-benefit ratio. The Egyptian government is already taking steps to increase energy efficiency in different areas; however, more solutions and actions are needed to help Egypt reach its emission reduction targets and avoid future energy crisis.

Financial Institutes:

Financial Institutes have a crucial role in increasing the use of energy-efficient technologies. They could offer green bonds, low-interest loans, grants, and other financing products. These financial solutions would encourage investments in energy-efficient technologies. They could also offer energy performance-based finance, in which the paybacks are linked to the energy savings achieved. This arrangement helps reduce the risk to the borrowers and ensures that the transaction is financially viable. Financing Institutes could also collect energy performance data from their clients' projects. This data collection begins with the projects' evaluation through either an owned certificate or an in-house developed building performance software.

If the transaction is a bond or energy performance-based finance, the institutes could track the actual savings of the energy efficiency technology applied to a building. The amount of data measured and collected could serve as case studies for future transactions, research, or technology enhancement. Finally, financial institutes could partner with the private sector and governments in energy-efficient projects as part of their Corporate Social Responsibility or, in some cases, a profitable development investment.

Developers/Investors:

The developers and investors could do major actions that could increase energy efficiency in Egypt significantly. These actions could include considering energy-efficient solutions in the initial design of the building. Many passive design techniques could be implemented through the building design that could impact its energy performance greatly. Energy simulation programs help designers reach optimum energy consumption levels. The role of the developers and investors in this stage lies in their ensuring the reaching of an energy-efficient building design. Through this stage, developers and investors should seek all available financial solutions to maximize the use of energy-efficient technologies in their buildings.

Investors could also invest in energy efficiency systems without owning the buildings through Energy Performance Contracts. These contracts enable the investor to finance the EETAs for the building owner in exchange for a share in the resulting energy savings. This solution could help building owners and tenants avoid paying high premium costs for the EETAs. The developers also could help researchers, manufacturers, and financing institutes by tracking their projects' energy performance and making the data available to the public. The lessons learned from each project are vital for the sustainability of energy-efficiency technology applications in buildings.

EETAs Manufacturers

Production companies and manufacturers could always contribute to the enhancement of the benefit-cost ratio of the EETAs. They should begin manufacturing their products locally and sourcing their raw materials from local vendors. The localization of the product helps in the stability and lowering of its cost and, relatively, its price. It also alleviates the risk of resource unavailability and transportation issues. In addition, producers could help the buyer make informed decisions through the usage of green labeling on their products. Green labels show basic emissions data of the product's manufacturing and the savings that the product could provide.

The companies could also help spread awareness of energy efficiency through their advertisements. A good advertisement has, usually, the power of influence. Research and Development should be at the core of all companies' structures. Energy technologies production companies should always aim through their R&D departments to produce technologies that achieve higher savings. Investing in research and innovative solutions could only benefit the companies and have positive outcomes for the products.

7.22 Further Studies

Further studies are needed to continue and validate the work of this study. This study considered the economic aspect of Energy Efficient Technology Applications without considering the social or environmental aspects. In future research the social aspects, like the users' behavior, the users' comfort, the stakeholder's perspective...etc., and the environmental aspects, like GHG emissions, pollution, locality...etc., would need to be tackled to assess the EETAs in a comprehensive context. Also, the benefits of increased comfort and GHG-reduced emissions were not calculated in this research and their calculation in future studies would affect the results.

During the energy simulation of the case studies, two elements were needed for more accurate and closer-to-reality results. First, the case studies were hypothetical, thus don't represent actual projects. In future studies, it would be useful if the case studies were actual buildings, and the data were measured in real-time instead of through simulation software. Second, the Energy Use Intensity (EUI) values were noticed to be different in each software.

There was no unified baseline for the commercial buildings' EUI. Therefore, it would be useful if future research could focus on identifying the EUI closest to Egypt's buildings' EUI, considering the buildings' location, typology, size, and occupancy rate.

This study focused on measuring the savings of each EETA individually without considering the change in savings when more than one technology is used in the building. So, more studies are needed to identify the effect of the combined use of different EETAs. The results of this research showed that the EETAs' savings and NPV vary based on the building size; nonetheless, the causality of this trend was not clear. Therefore, an extra investigation should be dedicated to the reasons behind the savings and NPVs' fluctuation based on the building size. Finally, more EETAs should be included in the next studies, as this study was limited to EETAs available in the used simulation programs.

References

- Global energy crisis – topics. IEA. (2022). Retrieved February 8, 2023, from https://www.iea.org/topics/global-energy-crisis
- Gabel, E. (2022, November 25). The energy crisis is reshaping power sector policies worldwide. IHS Markit. Retrieved February 8, 2023, from https://www.spglobal.com/commodityinsights/en/ci/research-analysis/the-energy-crisis-is-reshaping-power-sector-policies-worldwide.html
- Global Energy Perspective 2021 - McKinsey & Company. McKinsey. (2022). Retrieved February 8, 2023, from https://www.mckinsey.com/~/media/McKinsey/Industries/Oil%20and%20Gas/Our%20Insights/Global%20Energy%20Perspective%202021/Global-Energy-Perspective-2021-final.pdf
- Alhosainy, O. (2021, March 17). From crisis to abundance: Egypt's electricity sector on the right track. Business Today. Retrieved February 8, 2023, from https://www.businesstodayegypt.com/Article/7/423/From-Crisis-to-Abundance-Egypt%E2%80%99s-Electricity-Sector-on-the-Right
- Al-Anani, K. (2022, April 6). Russia's war on Ukraine: Egypt's limited room for maneuver. Arab Center Washington DC. Retrieved February 8, 2023, from https://arabcenterdc.org/resource/russias-war-on-ukraine-egypts-limited-room-for-maneuver/
- Monsef, J., Ahmed, M., & Mounir, Y. (2022, June). The Russia-Ukraine War's - Egypt Oil & Gas. Egypt Oil Gas. Retrieved February 8, 2023, from https://egyptoil-gas.com/reports/the-russia-ukraine-wars-impact-on-the-oil-gas-market/
- Global energy consumption. The world counts. (2022). Retrieved February 8, 2023, from https://www.theworldcounts.com/challenges/climate-change/energy/global-energy-consumption
- World electricity final consumption by sector, 1974-2017 – charts – Data & Statistics. IEA. (2019). Retrieved February 8, 2023, from https://www.iea.org/data-and-statistics/charts/world-electricity-final-consumption-by-sector-1974-2019
- IEA, (2022). (rep.). World Energy Outlook 2022. Retrieved February 8, 2023, from https://iea.blob.core.windows.net/assets/7e42db90-d8ea-459d-be1e-1256acd11330/WorldEnergyOutlook2022.pdf.
- Ritchie, H., Roser, M., & Rosado, P. (2022, October 27)(a). Energy mix. Our World in Data. Retrieved February 13, 2023, from https://ourworldindata.

org/energy-mix
- bp global. (2022). Primary energy: Energy economics. bp global. Retrieved February 13, 2023, from https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/primary-energy.html
- Ritchie, H., Roser, M., & Rosado, P. (2022, October 27)(b). Egypt: Energy Country Profile. Our World in Data. Retrieved February 13, 2023, from https://ourworldindata.org/energy/country/egypt#citation
- U.S. Energy Information Administration - EIA - independent statistics and analysis. International - U.S. Energy Information Administration (EIA). (2022, April 4). Retrieved February 13, 2023, from https://www.eia.gov/international/analysis/country/EGY
- Emissions – global energy & CO2 status report 2019 – analysis. IEA. (2019). Retrieved February 13, 2023, from https://www.iea.org/reports/global-energy-co2-status-report-2019/emissions
- Mehmetoglu, S. (2022, December 9). Understanding Egypt’s long path to decarbonization. ISPI. Retrieved February 13, 2023, from https://www.ispionline.it/en/publication/understanding-egypts-long-path-decarbonization-32912
- O’Malley, E., Scott, S., & Sorrell, S. (2003). Barriers to energy efficiency: Evidence from selected sectors (Ser. 47). Economic and Social Research Institute.
- Cleary, K., & Palmer, K. (2020, June). Energy efficiency 101. Resources for the Future. Retrieved February 18, 2023, from https://www.rff.org/publications/explainers/energy-efficiency-101/
- Yang, M., & Yu, X. (2016). Energy efficiency: Benefits for environment and society. Google Books. Springer. Retrieved February 18, 2023, from https://books.google.com/books?id=5RjGBgAAQBAJ&printsec=frontcover&source=gbs_atb#v=onepage&q&f=false.
- EDGE Cost Model. 2015. Version 1, An outline Methodology, EDGE IFC
- EDGE Methodology, 2022
- Guidehouse. 2022. How to develop a baseline to assess climate friendly buildings.
- Boardman, A. E., Greenberg, D. H., Vining, A. R., & Weimer, D. L. (2018). Cost-benefit analysis: Concepts and practice (5th ed.). Cambridge University Press.
- Hammitt, J. K., & Robinson, L. A. (2011). The income elasticity of the value per statistical life: Transferring estimates between high and low income populations. Journal of Benefit-Cost Analysis, 2(1), Article 2. doi: 10.2202/2152-2812.1008
- Shor, W., Packey, D. J., & Holt, T. (1995, March). A Manual for the Economic

Evaluation of Energy Efficiency and Renewable Energy Technologies: Vol. B-462-5173 [DE95000218]. National Renewable Energy Laboratory. https://nrel.gov/docs/legosti/old/5173.pdf
- Saltelli, A., & Annoni, P. (2010, January). sensitivity analysis. Research Gate. https://www.researchgate.net/publication/263688047_Sensitivity_Analysis
- Beebe, S. (2021, September 21). Scenario modeling: What you need to know. Synario. https://www.synario.com/scenario-modeling-what-you-need-to-know/
- As it bakes, Egypt looks to the cooling power of the sea for help - UNEP. UNEP. (2022, May). https://www.unep.org/news-and-stories/story/it-bakes-egypt-looks-cooling-power-sea-help
- Egypt Updated Nationally Determined Contribution. Egypt NDC. (2022, June). chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://unfccc.int/sites/default/files/NDC/2022-07/Egypt%20Updated%20NDC.pdf.pdf
- National Climate Change Strategy 2050. Egypt. (2022, June). Chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.amcham.org.eg/bic/pdf/sustainability-hub/NCCSprojects-conceptnotes-packagev3.pdf
- Hassan, A. A., El Dalla, N., Grözinger, J., & Surmeli-Anac, N. (2022, July 14). Cooling Sector Status Report Egypt. Guidehouse. https://www.coolupprogramme.org/knowledge-base/reports/cooling-sector-status-report-egypt/

Appendix A: Savings

Savings		EDGE			Build_Me			eQuest		
EETA		S	M	L	S	M	L	S	M	L
LED Bulbs	CFL luminous Efficacy 70 L/W	1.28%	1.43%	1.63%	0.35%	0.45%	0.65%	1.55%	1.66%	1.85%
	LED luminous Efficacy 100 L/W	6.16%	6.77%	8.04%	4.43%	5.74%	8.15%	5.91%	6.35%	7.09%
	LED luminous Efficacy 150 L/W	9.89%	10.88%	13%	0	0	0	9.48%	10.19%	11.42%
Light Controls	Auto On/Off	1.86%	2.19%	3.02%	2.10%	2.73%	3.88%	6.49%	5.15%	2.90%
	Continous Dimming	2.62%	3.00%	3.79%	2.10%	2.73%	3.88%	4.76%	3.77%	2.13%
	Timer Control with continuous dimming	2.75%	3.15%	4.09%	4.21%	5.47%	7.76%	0	0	0
WWR	35%	0.77%	0.61%	0.01%	2.22%	2.05%	1.15%	2.04%	1.61%	0.93%
	30%	1.49%	1.14%	0.04%	4.46%	4.10%	2.20%	4.07%	3.16%	1.84%
	25%	2.23%	1.64%	0.04%	6.76%	6.18%	3.40%	6.00%	4.70%	2.74%
Roof SRI	85 (White)	0.21%	0.19%	0.19%	1.05%	1.22%	0.73%	1.85%	2.18%	2.40%
	65	0.12%	0.12%	0.07%	0	0	0	0.95%	1.12%	1.20%
	55	0.07%	0.08%	0.01%	0	0	0	0.71%	0.84%	0.90%
Walls SRI	85	0.06%	0.09%	0.27%	3.70%	3.00%	0.85%	2.00%	1.72%	0.98%
	65	0.06%	0.07%	0.12%	0	0	0	1.04%	0.91%	0.50%
	55	0.05%	0.07%	0.03%	0	0	0	0.78%	0.68%	0.38%
External Shading	0.5 overhang on S elev. And 0.5 fin on W and E elev – AASF 0.18	0.09%	0.05%	0.10%	-5.26%	-4.00%	-1.48%	2.44%	1.87%	1.07%
	1 overhang on S elev. And 1 fin on W and E elev – AASF 0.29	-0.01%	-0.05%	0.19%	0	0	0	3.91%	3.10%	1.79%
	1.5 overhang on S elev. And 1.5 fin on W and E elev – AASF 0.36	-0.16%	-0.19%	0.21%	0	0	0	4.60%	3.66%	2.14%

Savings		**EDGE**			**Build_Me**			**eQuest**		
EETA		S	M	L	S	M	L	S	M	L
Roof Insulation	U-Value: 1.45	0.92%	0.75%	0.13%	-4%	-5.11%	-4.50%	0.87%	0.95%	0.94%
	U-Value: 1	1.79%	1.41%	0.28%	-2%	-2.20%	-2.10%	1.12%	1.04%	0.95%
	U-Value: 0.46	2.82%	2.19%	0.46%	1%	0.85%	0.67%	1.57%	1.52%	1.27%
Walls Insulation	U-Value: 1.45	1.62%	1.23%	0.10%	5.22%	4.52%	2.06%	1.17%	0.98%	0.52%
	U-Value: 1	3.28%	2.42%	0.22%	8.76%	7.50%	3.28%	1.27%	1.06%	0.57%
	U-Value: 0.46	5.17%	3.68%	0.28%	12.91%	10.92%	5.08%	1.35%	1.13%	0.59%
HVAC	Air Cooled Chiller – COP: 3	1.60%	1.19%	-2.36%	3.50%	1.29%	-0.36%	8.23%	7.90%	7.21%
	VRF Air Cooled – COP: 4	6.31%	5.07%	2.28%	27.64%	28.76%	21.19%	14.48%	13.89%	12.69%
	Water Cooled Chiller – COP: 5	4.43%	3.37%	2.26%	13.72%	11.80%	7.52%	18.14%	17.61%	16.04%
Windows	U-Value: 3.35	0.29%	0.24%	0.13%	0	0	0	0	0	0
	U-Value: 2.9	1.21%	0.96%	0.15%	0.32%	0.30%	0.11%	-0.02%	-0.03%	-0.02%
	U-Value: 2.45	2.08%	1.60%	0.12%	1.88%	1.76%	0.90%	-0.03%	-0.05%	-0.03%

Table 5: Savings of EETAs (by Author)

Appendix B: Incremental Cost Data

Cost of EETAs					**Small Buildings**	
EETA		Unit Price egp	Unit Price $	Unit	Qty	Total
LED Bulbs	CFL luminous Efficacy 70 L/W	75.00	$2.50	Bulb	866	$2,163.94
	LED luminous Efficacy 100 L/W	75.00	$2.50	Bulb	606	$1,514.76
	LED luminous Efficacy 150 L/W	90.00	$3	Bulb	404	$1,211.81
Light Controls	Auto On/Off	600.00	$ 20	Switch	173	$3,462.30
	Continous Dimming	600.00	$ 20	Switch	121	$2,423.61
	Timer Control with continuous dimming	1,500.00	$ 50	Switch	81	$4,039.35
WWR	35%	3,000.00	$ 100	Window	532	$53,224.50
	30%	3,000.00	$ 100	Window	456	$45,621.00
	25%	3,000.00	$ 100	Window	380	$38,017.50
Roof SRI	85 (White tiles)	300.00	$10.00	m2	808	$8,080.00
	65 (Medium Grey tiles)	300.00	$10.00	m2	808	$8,080.00
	55 (Medium Beige tiles)	300.00	$10.00	m2	808	$8,080.00
Walls SRI	85 (White tiles)	15.00	$ 0.5	m2	1,824.84	$912.42
	65 (Medium Grey tiles)	15.00	$ 0.5	m2	1,824.84	$912.42
	55 (Medium Beige tiles)	15.00	$ 0.5	m2	1,824.84	$912.42
External Shading	0.5 overhang on S elev. And 0.5 fin on W and E elev – AASF 0.18	1,500.00	$ 50	window	532	$26,612.25
	1 overhang on S elev. And 1 fin on W and E elev – AASF 0.29	3,000.00	$ 100	window	456	$45,621.00
	1.5 overhang on S elev. And 1.5 fin on W and E elev – AASF 0.36	4,500.00	$ 150	window	380	$57,026.25
Roof Insulation	U-Value: 1.45	180.00	$6.00	m2	808	$4,848.00
	U-Value: 1	300.00	$10.00	m2	808	$8,080.00
	U-Value: 0.46	450.00	$15	m2	808	$12,120.00
Wall Insulation	U-Value: 1.45	180.00	$6.00	m2	1,824.84	$10,949.04
	U-Value: 1	300.00	$10.00	m2	1,824.84	$18,248.40
	U-Value: 0.46	450.00	$15	m2	1,824.84	$27,372.60
HVAC	Air Cooled Chiller – COP: 3	7,500,000.00	$ 250,000	unit	1	$250,000.00
	VRF Air Cooled – COP: 4	15,000,000.00	$ 500,000	unit	1	$500,000.00
	Water Cooled Chiller – COP: 5	9,000,000.00	$ 300,000	unit	1	$300,000.00
Windows	U-Value: 3.35	4,500.00	$150	Window	608	$91,242.00
	U-Value: 2.9	6,000.00	$200	Window	608	$121,656.00
	U-Value: 2.45	9,000.00	$300	Window	608	$182,484.00

Cost of EETAs					**Medium Buildings**	
EETA		Unit Price egp	Unit Price $	Unit	Qty	Total
LED Bulbs	CFL luminous Efficacy 70 L/W	75.00	$2.50	Bulb	2,363	$5,908.63
	LED luminous Efficacy 100 L/W	75.00	$2.50	Bulb	1,654	$4,136.04
	LED luminous Efficacy 150 L/W	90.00	$3	Bulb	1,103	$3,309
Light Controls	Auto On/Off	600.00	$ 20	Switch	473	$9,454
	Continous Dimming	600.00	$ 20	Switch	331	$6,618
	Timer Control with continuous dimming	1,500.00	$ 50	Switch	221	$11,029
WWR	35%	3,000.00	$ 100	Window	734	$73,364
	30%	3,000.00	$ 100	Window	629	$62,883
	25%	3,000.00	$ 100	Window	524	$52,403
Roof SRI	85 (White tiles)	300.00	$10.00	m2	1,654	$16,544
	65 (Medium Grey tiles)	300.00	$10.00	m2	1,654	$16,544
	55 (Medium Beige tiles)	300.00	$10.00	m2	1,654	$16,544
Walls SRI	85 (White tiles)	15.00	$ 0.5	m2	2,515.32	$1,258
	65 (Medium Grey tiles)	15.00	$ 0.5	m2	2,515.32	$1,258
	55 (Medium Beige tiles)	15.00	$ 0.5	m2	2,515.32	$1,258
External Shading	0.5 overhang on S elev. And 0.5 fin on W and E elev – AASF 0.18	1,500.00	$ 50	window	734	$36,682
	1 overhang on S elev. And 1 fin on W and E elev – AASF 0.29	3,000.00	$ 100	window	629	$62,883
	1.5 overhang on S elev. And 1.5 fin on W and E elev – AASF 0.36	4,500.00	$ 150	window	524	$78,604
Roof Insulation	U-Value: 1.45	180.00	$6.00	m2	1,654	$9,927
	U-Value: 1	300.00	$10.00	m2	1,654	$16,544
	U-Value: 0.46	450.00	$15	m2	1,654	$24,816
Wall Insulation	U-Value: 1.45	180.00	$6.00	m2	2,515.32	$15,092
	U-Value: 1	300.00	$10.00	m2	2,515.32	$25,153
	U-Value: 0.46	450.00	$15	m2	2,515.32	$37,730
HVAC	Air Cooled Chiller – COP: 3	7,500,000.00	$ 250,000	unit	3	$750,000
	VRF Air Cooled – COP: 4	15,000,000.00	$ 500,000	unit	3	$1,500,000
	Water Cooled Chiller – COP: 5	9,000,000.00	$ 300,000	unit	4	$1,200,000
Windows	U-Value: 3.35	4,500.00	$150	Window	838	$125,766
	U-Value: 2.9	6,000.00	$200	Window	838	$167,688
	U-Value: 2.45	9,000.00	$300	Window	838	$251,532

Cost of EETAs					**Large Buildings**	
EETA		Unit Price egp	Unit Price $	Unit	Qty	Total
LED Bulbs	CFL luminous Efficacy 70 L/W	75.00	$2.50	Bulb	13,652	$34,131.00
	LED luminous Efficacy 100 L/W	75.00	$2.50	Bulb	9,557	$23,891.70
	LED luminous Efficacy 150 L/W	90.00	$3	Bulb	6,371	$19,113
Light Controls	Auto On/Off	600.00	$ 20	Switch	2,730	$54,610
	Continous Dimming	600.00	$ 20	Switch	1,911	$38,227
	Timer Control with continuous dimming	1,500.00	$ 50	Switch	1,274	$63,711
WWR	35%	3,000.00	$ 100	Window	1,136	$113,642
	30%	3,000.00	$ 100	Window	974	$97,407
	25%	3,000.00	$ 100	Window	812	$81,173
Roof SRI	85 (White tiles)	300.00	$10.00	m2	5,881	$58,810.00
	65 (Medium Grey tiles)	300.00	$10.00	m2	5,881	$58,810.00
	55 (Medium Beige tiles)	300.00	$10.00	m2	5,881	$58,810.00
Walls SRI	85 (White tiles)	15.00	$ 0.5	m2	3,896.28	$1,948.14
	65 (Medium Grey tiles)	15.00	$ 0.5	m2	3,896.28	$1,948.14
	55 (Medium Beige tiles)	15.00	$ 0.5	m2	3,896.28	$1,948.14
External Shading	0.5 overhang on S elev. And 0.5 fin on W and E elev – AASF 0.18	1,500.00	$ 50	window	1,136	$56,820.75
	1 overhang on S elev. And 1 fin on W and E elev – AASF 0.29	3,000.00	$ 100	window	974	$97,407.00
	1.5 overhang on S elev. And 1.5 fin on W and E elev – AASF 0.36	4,500.00	$ 150	window	812	$121,758.75
Roof Insulation	U-Value: 1.45	180.00	$6.00	m2	5,881	$35,286.00
	U-Value: 1	300.00	$10.00	m2	5,881	$58,810.00
	U-Value: 0.46	450.00	$15	m2	5,881	$88,215.00
Wall Insulation	U-Value: 1.45	180.00	$6.00	m2	3,896.28	$23,377.68
	U-Value: 1	300.00	$10.00	m2	3,896.28	$38,962.80
	U-Value: 0.46	450.00	$15	m2	3,896.28	$58,444.20
HVAC	Air Cooled Chiller – COP: 3	7,500,000.00	$ 250,000	unit	6	$1,500,000
	VRF Air Cooled – COP: 4	15,000,000.00	$ 500,000	unit	6	$3,000,000
	Water Cooled Chiller – COP: 5	9,000,000.00	$ 300,000	unit	15	$4,500,000
Windows	U-Value: 3.35	4,500.00	$150	Window	1,299	$194,814.00
	U-Value: 2.9	6,000.00	$200	Window	1,299	$259,752.00
	U-Value: 2.45	9,000.00	$300	Window	1,299	$389,628.00

Table 6: Cost of EETAs (by Author)

Cost Variance (Baseline – EETA)		Small Building	Medium Building	Large Building
EETA		Total	Total	Total
LED Bulbs	CFL luminous Efficacy 70 L/W	$299.62	$818.12	$4,725.83
	LED luminous Efficacy 100 L/W	($349.56)	($954.47)	($5,513.47)
	LED luminous Efficacy 150 L/W	($652.51)	($1,781.68)	($10,291.81)
Light Controls	Auto On/Off	$3,462.30	$9,453.81	$54,609.60
	Continous Dimming	$2,423.61	$6,617.67	$38,226.72
	Timer Control with continuous dimming	$4,039.35	$11,029.45	$63,711.20
WWR	35%	($7,603.50)	($10,480.50)	($16,234.50)
	30%	($15,207.00)	($20,961.00)	($32,469.00)
	25%	($22,810.50)	($31,441.50)	($48,703.50)
Roof SRI	85 (White tiles)	$0.00	$0.00	$0.00
	65 (Medium Grey tiles)	$0.00	$0.00	$0.00
	55 (Medium Beige tiles)	$0.00	$0.00	$0.00
Walls SRI	85 (White tiles)	$0.00	$0.00	$0.00
	65 (Medium Grey tiles)	$0.00	$0.00	$0.00
	55 (Medium Beige tiles)	$0.00	$0.00	$0.00
External Shading	0.5 overhang on S elev. And 0.5 fin on W and E elev – AASF 0.18	$26,612.25	$36,681.75	$56,820.75
	1 overhang on S elev. And 1 fin on W and E elev – AASF 0.29	$45,621.00	$62,883.00	$97,407.00
	1.5 overhang on S elev. And 1.5 fin on W and E elev – AASF 0.36	$57,026.25	$78,603.75	$121,758.75
Roof Insulation	U-Value: 1.45	$1,616.00	$3,308.84	$11,762.00
	U-Value: 1	$4,848.00	$9,926.51	$35,286.00
	U-Value: 0.46	$8,888.00	$18,198.59	$64,691.00
Wall Insulation	U-Value: 1.45	$3,649.68	$5,030.64	$7,792.56
	U-Value: 1	$10,949.04	$15,091.92	$23,377.68
	U-Value: 0.46	$20,073.24	$27,668.52	$42,859.08
HVAC	Air Cooled Chiller – COP: 3	$200,000.00	$650,000.00	$1,350,000.00
	VRF Air Cooled – COP: 4	$450,000.00	$1,400,000.00	$2,850,000.00
	Water Cooled Chiller – COP: 5	$250,000.00	$1,100,000.00	$4,350,000.00
Windows	U-Value: 3.35	$12,165.60	$16,768.80	$25,975.20
	U-Value: 2.9	$42,579.60	$58,690.80	$90,913.20
	U-Value: 2.45	$103,407.60	$142,534.80	$220,789.20

Table 7: Incremental Cost of EETAs (by Author)

Appendix C: Net Present Value

Cost			Small Buildings NPV per discount rate					
	EETA	lifetime	Cost	Savings/year	3%	7%	10%	16%
LED Bulbs	CFL luminous Efficacy 70 L/W	10.00	$299.62	325.41	2,476	1,986	1,700	1,273
	LED luminous Efficacy 100 L/W	15.00	($349.56)	1,688.47	20,506	15,728	13,192	9,764
	LED luminous Efficacy 150 L/W	15.00	($652.51)	1,982.17	24,315	18,706	15,729	11,704
Light Controls	Auto On/Off	15.00	$3,462.30	1,069.37	9,304	6,277	4,671	2,500
	Continous Dimming	15.00	$2,423.61	970.10	9,157	6,412	4,955	2,985
	Timer Control with continuous dimming	15.00	$4,039.35	712.23	4,463	2,448	1,378	-68
WWR	WWR 35%	30.00	($7,603.50)	514.73	17,692	13,991	12,456	10,783
	WWR 30%	30.00	($15,207.00)	1,025.36	35,305	27,931	24,873	21,541
	WWR 25%	30.00	($22,810.50)	1,533.95	52,877	41,845	37,271	32,286
Roof SRI	Roof SRI 85 (White tiles)	50.00	$0.00	318.25	8,189	4,392	3,155	1,988
	Roof SRI 65 (Medium Grey tiles)	50.00	$0.00	109.49	2,817	1,511	1,086	684
	Roof SRI 55 (Medium Beige tiles)	50.00	$0.00	79.82	2,054	1,102	791	499
Walls SRI	Wall SRI 85 (White tiles)	10.00	$0.00	589.43	5,028	4,140	3,622	2,849
	Wall SRI 65 (Medium Grey tiles)	10.00	$0.00	112.56	960	791	692	544
	Wall SRI 55 (Medium Beige tiles)	10.00	$0.00	84.94	725	597	522	411
External Shading	0.5 overhang on S elev. And 0.5 fin on W and E elev – AASF 0.18	30.00	$26,612.25	(279.37)	-32,088	-30,079	-29,246	-28,338
	1 overhang on S elev. And 1 fin on W and E elev – AASF 0.29	30.00	$45,621.00	399.09	-37,799	-40,669	-41,859	-43,156
	1.5 overhang on S elev. And 1.5 fin on W and E elev – AASF 0.36	30.00	$57,026.25	454.35	-48,121	-51,388	-52,743	-54,220
Roof Insulation	Roof U-Value: 1.45	50.00	$1,616.00	(226.15)	-7,435	-4,737	-3,858	-3,029
	Roof U-Value: 1	50.00	$4,848.00	93.12	-2,452	-3,563	-3,925	-4,266
	Roof U-Value: 0.46	50.00	$8,888.00	551.57	5,304	-1,276	-3,419	-5,443
Wall Insulation	Wall U-Value: 1.45	50.00	$3,649.68	819.68	17,440	7,662	4,477	1,470
	Wall U-Value: 1	50.00	$10,949.04	1,362.04	24,096	7,848	2,555	-2,441
	Wall U-Value: 0.46	50.00	$20,073.24	1,988.31	31,085	7,367	-360	-7,654
HVAC	Air Cooled Chiller – COP: 3	15.00	$200,000.00	1,364.08	-183,716	-187,576	-189,625	-192,395
	VRF Air Cooled – COP: 4	10.00	$450,000.00	4,955.92	-407,725	-415,192	-419,548	-426,047
	Water Cooled Chiller – COP: 5	20.00	$250,000.00	3,713.62	-194,751	-210,658	-218,384	-227,983
Windows	Windows U-Value: 3.35	30.00	$12,165.60	29.68	-11,584	-11,797	-11,886	-11,982
	Windows U-Value: 2.9	30.00	$42,579.60	155.03	-39,541	-40,656	-41,118	-41,622
	Windows U-Value: 2.45	30.00	$103,407.60	402.16	-95,525	-98,417	-99,616	-100,923

Cost		Medium Buildings NPV per discount rate						
EETA		lifetime	Cost	Savings/year	3%	7%	10%	16%
LED Bulbs	CFL luminous Efficacy 70 L/W	10.00	$818.12	847.26	6,409	5,133	4,388	3,277
	LED luminous Efficacy 100 L/W	15.00	($954.47)	4,513.92	54,841	42,067	35,288	26,122
	LED luminous Efficacy 150 L/W	15.00	($1,781.68)	5,042.86	61,983	47,712	40,138	29,898
Light Controls	Auto On/Off	15.00	$9,453.81	2,410.14	19,318	12,498	8,878	3,984
	Continous Dimming	15.00	$6,617.67	2,273.72	20,526	14,091	10,676	6,059
	Timer Control with continuous dimming	15.00	$11,029.45	2,063.10	13,600	7,761	4,663	473
WWR	WWR 35%	30.00	($10,480.50)	1,021.98	30,512	23,162	20,115	16,793
	WWR 30%	30.00	($20,961.00)	2,010.44	60,367	45,909	39,913	33,380
	WWR 25%	30.00	($31,441.50)	2,996.52	90,175	68,625	59,689	49,952
Roof SRI	Roof SRI 85 (White tiles)	50.00	$0.00	859.23	22,108	11,858	8,519	5,367
	Roof SRI 65 (Medium Grey tiles)	50.00	$0.00	296.78	7,636	4,096	2,943	1,854
	Roof SRI 55 (Medium Beige tiles)	50.00	$0.00	220.19	5,665	3,039	2,183	1,375
Walls SRI	Wall SRI 85 (White tiles)	10.00	$0.00	1,151.22	9,820	8,086	7,074	5,564
	Wall SRI 65 (Medium Grey tiles)	10.00	$0.00	234.55	2,001	1,647	1,441	1,134
	Wall SRI 55 (Medium Beige tiles)	10.00	$0.00	179.50	1,531	1,261	1,103	868
External Shading	0.5 overhang on S elev. And 0.5 fin on W and E elev – AASF 0.18	30.00	$36,681.75	(497.82)	-46,439	-42,859	-41,375	-39,757
	1 overhang on S elev. And 1 fin on W and E elev – AASF 0.29	30.00	$62,883.00	729.98	-48,575	-53,825	-56,002	-58,374
	1.5 overhang on S elev. And 1.5 fin on W and E elev – AASF 0.36	30.00	$78,603.75	830.50	-62,325	-68,298	-70,775	-73,474
Roof Insulation	Roof U-Value: 1.45	50.00	$3,308.84	(816.14)	-24,308	-14,572	-11,401	-8,407
	Roof U-Value: 1	50.00	$9,926.51	59.83	-8,387	-9,101	-9,333	-9,553
	Roof U-Value: 0.46	50.00	$18,198.59	1,091.38	9,882	-3,137	-7,378	-11,382
Wall Insulation	Wall U-Value: 1.45	50.00	$5,030.64	1,610.75	36,414	17,199	10,940	5,031
	Wall U-Value: 1	50.00	$15,091.92	2,627.94	52,524	21,176	10,964	1,323
	Wall U-Value: 0.46	50.00	$27,668.52	3,764.79	69,199	24,288	9,659	-4,153
HVAC	Air Cooled Chiller – COP: 3	15.00	$650,000.00	2,484.33	-620,342	-627,373	-631,104	-636,149
	VRF Air Cooled – COP: 4	10.00	$1,400,000.00	11,421.23	-1,302,575	-1,319,782	-1,329,821	-1,344,799
	Water Cooled Chiller – COP: 5	20.00	$1,100,000.00	7,845.52	-983,279	-1,016,884	-1,033,207	-1,053,485
Windows	Windows U-Value: 3.35	30.00	$16,768.80	57.44	-15,643	-16,056	-16,227	-16,414
	Windows U-Value: 2.9	30.00	$58,690.80	294.39	-52,921	-55,038	-55,916	-56,872
	Windows U-Value: 2.45	30.00	$142,534.80	792.21	-127,007	-132,704	-135,067	-137,641

Cost			Large Buildings NPV per discount rate					
EETA		lifetime	Cost	Savings/year	3%	7%	10%	16%
LED Bulbs	CFL luminous Efficacy 70 L/W	10.00	$4,725.83	4,528.58	33,904	27,081	23,100	17,162
	LED luminous Efficacy 100 L/W	15.00	($5,513.47)	25,526.73	310,250	238,009	199,672	147,837
	LED luminous Efficacy 150 L/W	15.00	($10,291.81)	26,776.75	329,951	254,172	213,958	159,584
Light Controls	Auto On/Off	15.00	$54,609.60	10,745.79	73,673	43,262	27,124	5,303
	Continous Dimming	15.00	$38,226.72	10,745.79	90,056	59,645	43,507	21,686
	Timer Control with continuous dimming	15.00	$63,711.20	12,993.63	91,406	54,634	35,119	8,734
WWR	WWR 35%	30.00	($16,234.50)	2,291.70	61,153	44,672	37,838	30,391
	WWR 30%	30.00	($32,469.00)	4,473.76	120,157	87,984	74,643	60,104
	WWR 25%	30.00	($48,703.50)	6,776.42	181,524	132,792	112,584	90,563
Roof SRI	Roof SRI 85 (White tiles)	50.00	$0.00	3,640.41	93,667	50,240	36,094	22,739
	Roof SRI 65 (Medium Grey tiles)	50.00	$0.00	1,392.57	35,830	19,218	13,807	8,698
	Roof SRI 55 (Medium Beige tiles)	50.00	$0.00	997.82	25,674	13,771	9,893	6,233
Walls SRI	Wall SRI 85 (White tiles)	10.00	$0.00	2,302.67	19,642	16,173	14,149	11,129
	Wall SRI 65 (Medium Grey tiles)	10.00	$0.00	679.84	5,799	4,775	4,177	3,286
	Wall SRI 55 (Medium Beige tiles)	10.00	$0.00	449.57	3,835	3,158	2,762	2,173
External Shading	0.5 overhang on S elev. And 0.5 fin on W and E elev – AASF 0.18	30.00	$56,820.75	(339.92)	-63,483	-61,039	-60,025	-58,920
	1 overhang on S elev. And 1 fin on W and E elev – AASF 0.29	30.00	$97,407.00	2,171.09	-54,853	-70,466	-76,940	-83,996
	1.5 overhang on S elev. And 1.5 fin on W and E elev – AASF 0.36	30.00	$121,758.75	2,576.80	-71,252	-89,783	-97,468	-105,841
Roof Insulation	Roof U-Value: 1.45	50.00	$11,762.00	(3,761.03)	-108,532	-63,667	-49,052	-35,254
	Roof U-Value: 1	50.00	$35,286.00	(953.96)	-59,831	-48,451	-44,744	-41,245
	Roof U-Value: 0.46	50.00	$64,691.00	2,631.62	3,020	-28,373	-38,599	-48,253
Wall Insulation	Wall U-Value: 1.45	50.00	$7,792.56	2,938.64	67,818	32,763	21,344	10,563
	Wall U-Value: 1	50.00	$23,377.68	4,462.79	91,449	38,212	20,870	4,498
	Wall U-Value: 0.46	50.00	$42,859.08	6,524.23	125,008	47,180	21,827	-2,107
HVAC	Air Cooled Chiller – COP: 3	15.00	$1,350,000.00	4,923.32	-1,291,226	-1,305,159	-1,312,553	-1,322,550
	VRF Air Cooled – COP: 4	10.00	$2,850,000.00	39,649.76	-2,511,780	-2,571,517	-2,606,369	-2,658,364
	Water Cooled Chiller – COP: 5	20.00	$4,350,000.00	28,311.86	-3,928,791	-4,050,064	-4,108,965	-4,182,143
Windows	Windows U-Value: 3.35	30.00	$25,975.20	142.55	-23,181	-24,206	-24,631	-25,095
	Windows U-Value: 2.9	30.00	$90,913.20	263.16	-85,755	-87,648	-88,432	-89,288
	Windows U-Value: 2.45	30.00	$220,789.20	1,085.54	-215,631	-217,524	-218,308	-219,164

Table 8: Net Present Values (by Author)

بحث عن فرص تحسين نسبة التكلفة والمنفعة لتطبيقات تكنولوجيا كفاءة الطاقة في المباني المكتبية في مصر

منة الله عبد الجواد

خلاصة

يستهلك قطاع البناء نسبة عالية من استهلاك الطاقة في العالم ومصر (30٪ و 50٪ على التوالي). يتمتع قطاع البناء في مصر بإمكانيات كبيرة لخفض استهلاكه وزيادة كفاءة استخدام الطاقة. تم استخدام تطبيقات التكنولوجيا الموفرة للطاقة في العديد من المباني لتحقيق وفورات في الطاقة وتقليل البصمة الكربونية للمبنى. في مصر ، كما هو الحال في العديد من البلدان الأخرى ، تشتهر تطبيقات التكنولوجيا الموفرة للطاقة بتكلفتها الأولية العالية ، مما يجعلها ليست الخيار الأول للعديد من المطورين. بالإضافة إلى ذلك ، نظرًا لوجود فجوة في المعرفة في إيجاد طرق لتقليل التكاليف الأولية لتطبيقات التكنولوجيا الموفرة للطاقة في المباني المكتبية مع زيادة فوائدها في مصر ، فمن الصعب تسريع الزيادة البطيئة للمباني الموفرة للطاقة في مصر.

تستكشف هذه الدراسة الفرص المحتملة لتحسين تكلفة منافع هذه التطبيقات التكنولوجيا الموفرة للطاقة وتسلط الضوء على طرق تقليل التكلفة الأولية لـلتطبيقات التكنولوجيا الموفرة للطاقة وزيادة فوائدها. كما أنها توفر تصنيفًا لـلتطبيقات التكنولوجيا الموفرة للطاقة بناءً على قدرتها على تكاليفها وتوفيرها في مباني المكاتب في مصر. سيساعد هذا في تحديد التحديات التي تعيق زيادة الاعتماد على تطبيقات التكنولوجيا الموفرة للطاقة في المباني وستساعد هذه الدراسة في توجيه المطورين والمستأجرين نحو تطبيقات التكنولوجيا الموفرة للطاقة ذات الأسعار المعقولة والتي من شأنها أن تحقق توفير في الطاقة المرغوب بناءً على حجم المبنى.

تستخدم هذه الدراسة ثلاثة برامج عامة ومجانية: EDGE و Build_Me و eQuest لمحاكاة الطاقة لتطبيقات التكنولوجيا الموفرة للطاقة. تم اختيار ثلاثة أحجام افتراضية لمبنى المكاتب لإجراء عمليات المحاكاة. تم حساب التكلفة الإضافية لكل تطبيق التكنولوجيا الموفر للطاقة بناءً على سعر السوق. ثم تم استخدام نتائج التوفير والتكلفة لحساب صافي القيمة الحالية لكل تطبيق التكنولوجيا الموفر للطاقة وتصنيفها وفقًا لتكلفتها المنخفضة / العالية والمدخرات المنخفضة / المرتفعة. تظهر نتائج الدراسة أن أنظمة التبريد وعزل الجدار وأدوات التحكم في الإضاءة هي تطبيقات التكنولوجيا الموفرة للطاقة ذات التكلفة العالية والتوفير العالي وهي الأكثر استحقاقًا لمزيد من التحسينات لتقليل تكلفتها وزيادة فوائدها. تُظهر الدراسة أيضًا أن المصابيح الموفرة للطاقة ونسبة النوافذ إلى الجدار المنخفضة لها تكلفة منخفضة وتنتج مدخرات عالية ، لذا يمكن استخدامها بشكل مباشر في المباني في مصر لتحسين أداء الطاقة.

الكلمات المفتاحية: كفاءة الطاقة ، التكلفة المنفعة ، تطبيقات التكنولوجيا الموفرة للطاقة ، مباني المكاتب

إقرار

هذه الرسالة مقدمة في جامعة عين شمس وجامعة شوتجارت للحصول على درجة العمران المتكامل والتصميم المستدام. إن العمل الذي تحويه هذه الرسالة قد تم إنجازه بمعرفة الباحث سنة ...

هذا ويقر الباحث أن العمل المقدم هو خلاصة بحثه الشخصي وأنه قد اتبع الإسلوب العلمي السليم في الإشارة إلى المواد المؤخوذه من المراجع العلمية كلٌ في مكانه في مختلف أجزاء الرسالة..

وهذا إقرار مني بذلك، ، ،

التوقيع:

الباحث:

التاريخ: /

بحث عن فرص تحسين نسبة التكلفة والمنفعة لتطبيقات تكنولوجيا كفاءة الطاقة في المباني المكتبية في مصر

مقدمة للحصول على درجة الماجستير في العمران المتكامل والتصميم المستدام

أعداد: **منة الله محمد محمود عبد الجواد**

لجنة أشراف

.أ.د محمد صالحين
أستاذ التخطيط والتصميم المتكامل
جامعة عين شمس

أ.د. دناي هرنانديز كورتيس
أستاذ مستقبل الابتكار في المجتمع
جامعة ولاية اريزونا

أ.د خالد طربيه
أستاذ هندسة عمارة
جامعة الامريكية بالقاهرة

لجنة الحكم
أ.د.........الممتحن الخارجي
أستاذ.............
جامعة ....

أ.د.........
أستاذ.............
جامعة ....

أ.د.........
أستاذ.............
جامعة ....

التوقيع

تاريخ المناقشة:...............

الدراسات العليا

ختم الإجازة
موافقة مجلس الكلية .../.../...

أجيزت الرسالة بتاريخ:.............
موافقة مجلس الجامعة .../.../...

جامعة عين شـــــمس

MM/DD/YYYY

جامعة عين شمس

بحث عن فرص تحسين نسبة التكلفة والمنفعة لتطبيقات تكنولوجيا كفاءة الطاقة في المباني المكتبية في مصر

رسالة مقدمة للحصول على درجة الماجستير في العمران المتكامل والتصميم المستدام

إعداد

منة الله محمد محمود عبد الجواد

المشرفون

أ.د محمد صالحين.
أستاذ التخطيط والتصميم المتكامل
جامعة عين شمس

أ.د. دناي هرنانديز كورتيس
أستاذ مستقبل الابتكار في المجتمع
جامعة ولاية اريزونا

أ.د خالد طربيه
أستاذ هندسة عمارة
جامعة الامريكية بالقاهرة

24 July 2023