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Getting to Net Zero Energy Buildings: A Holistic Techno-ecological Modeling Approach

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GETTING TO NET ZERO ENERGY BUILDINGS: A HOLISTIC TECHNO-ECOLOGICAL MODELING APPROACH

by

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Major Professor: Omer Tatari

ABSTRACT

Buildings in the United States are responsible for more than 40% of the primary energy and 70% of electricity usage and greatly in CO_2 emission by about 39%, more than any other sector including transportation and industry sectors. This energy consumption is expected to grow mainly due to increasing trends in new buildings construction. Rising energy prices alongside with energy independencies, limited resources, and climate change have made the current situation even worse. An Energy Efficient (EE) building is able to reduce the heating and cooling load significantly compared with a code compliant building. Furthermore, integrating renewable energy sources in the building energy portfolio could drive the building's grid reliance further down. Such buildings that are able to passively save and actively produce energy are called Net Zero Energy Buildings (NZEB). Despite all new energy efficient technologies, reaching NZEB is challenging due to high first cost of super-efficient measures and renewable energy sources as well as integration of the newly on-site generated electricity to the grid. Achieving NZEB without looking at its surrounding environment may result in sub-optimal solutions. Currently, 95% of American households own a car, and with the help of newly introduced Vehicle to Home (V2H) technologies, building, vehicle, renewable energy sources, and ecological environment can work together as a techno-ecological system to fulfill the requirement of an NZEB ecosystem.

Due to the great flexibility of electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) in interacting with the power grid, they will play a significant role in the future of the power system. In a large scale, an organized fleet of EVs can be considered as reliable and flexible power storage for a set of building blocks or in a smaller scale, individual EV owners can use their own vehicles as a source of power alongside with other sources of power. To this end, V2H

technologies can utilize idle EV battery power as an electricity storage tool to mitigate fluctuations in renewable electric power supply, to provide electricity for the building during the peak time, and to help in supplying electricity during emergency situation and power outage. V2H is said to be the solution to a successful integration of renewables and at the same time maintaining the integrity of the grid. This happens through depleting the stored power in the battery of EV and then charging the battery when the demand is low, using the electricity provided by grid or renewables. Government incentives can play an important role in employing this technology by buying out the high first time cost request. According to Energy Information Administration (EIA), U.S. residential utility customers consume 29.95 kWh electricity on average per household-day. With the current technology, EV batteries could store up to 30 kWh electricity. As a result, even for a code compliant house, a family could use EV battery as a source of energy for one normal day operation. For an energy efficient home, there could even be a surplus of energy that could be transferred to the grid. In summary, Achieving NZEB is facing various obstacles and removing these barriers require a more holistic view on a greater system and environment, where a building interacts with on-site renewable energy sources, EV, and its surrounded ecological environment.

This dissertation aims to utilize the application of Vehicle to Home technology to reach NZEB by developing two new models in two phases; the macro based excel model (NZEB-VBA) and agent based model (NZEB-ABM). Using these two models, homeowners can calculate the savings through implementing abovementioned technologies which can be considered as a motivation to move toward greener buildings. In the first step, an optimization analysis is performed first to select the best design alternatives for an energy-efficient building under the relevant economic and environmental constraints. Next, solar photovoltaic sources are used to

supply the building’s remaining energy demand and thereby minimize the building’s grid reliance. Finally, Vehicle to Home technology is coupled with the renewable energy source as a substitute for power from the grid. The whole algorithm for this process will be running in the visual basic environment.

In the second phase of the study, the focus is more on the dynamic interaction of different components of the system with each other. Although the general procedure is the same, the modeling will take place in a different environment. Showing the status of different parts of the system at any specific time, changing the values of different parameters of the system and observing the results, and investigating the impact of each parameter’s on overall behavior of the system are among the advantages of the agent based model. Having real time data can greatly enhance the capabilities of this system. The results indicate that, with the help of energy-efficient design features and a properly developed algorithm to draw electricity from EV and solar energy, it is possible to reduce the required electricity from the power grid by 59% when compared to a standard energy-efficient building and by as much as 90% when compared to a typical code-compliant building. This thereby reduces the electricity cost by 1.55 times the cost of the conventional method of drawing grid electricity. This savings can compensate the installation costs of solar panels and other technologies necessary for a Net Zero Energy Building. In the last phase of the study, a regional analysis will be performed to investigate the effect of different weather conditions, traffic situation and driving behavior on the behavior of this system.

To my lovely parents

For all of your support and encouragement

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CHAPTER ONE: INTRODUCTION[1]

1.1 Research Problem Statement

Historical data shows that the share of U.S. primary energy consumption for buildings has increased from 33.7% in 1980 to 41.2% in 2012 and that the same increasing trend is expected to continue in the future as the share of U.S. energy consumption for buildings is predicted to reach up to 42.1% in 2035 [1]. This is more than any other sector including industry and transportation sectors. The building's energy consumption becomes more critical considering the major factors affecting energy demand such as population growth which determines the number of community buildings and increased size and service demands of buildings[2]. Figure 1, clearly shows how the share of residential and commercial building's energy consumption will increase over time from 40 quadrillion Btu in 2008 to 47 quadrillion Btu in 2035.

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[1] A part of this dissertation also appeared in:
-Alirezaei, M., Noori, M., and Tatari, O. "Getting to net zero energy building: Investigating the role of vehicle to home technology." Energy and Buildings 130 (2016): 465-476.
-Alirezaei, M., Noori, M., and Tatari, O. "Application of Vehicle to Home Technology to Achieve a Net Zero Energy Building: An Agent Based Modeling Approach." Energy (In revision)

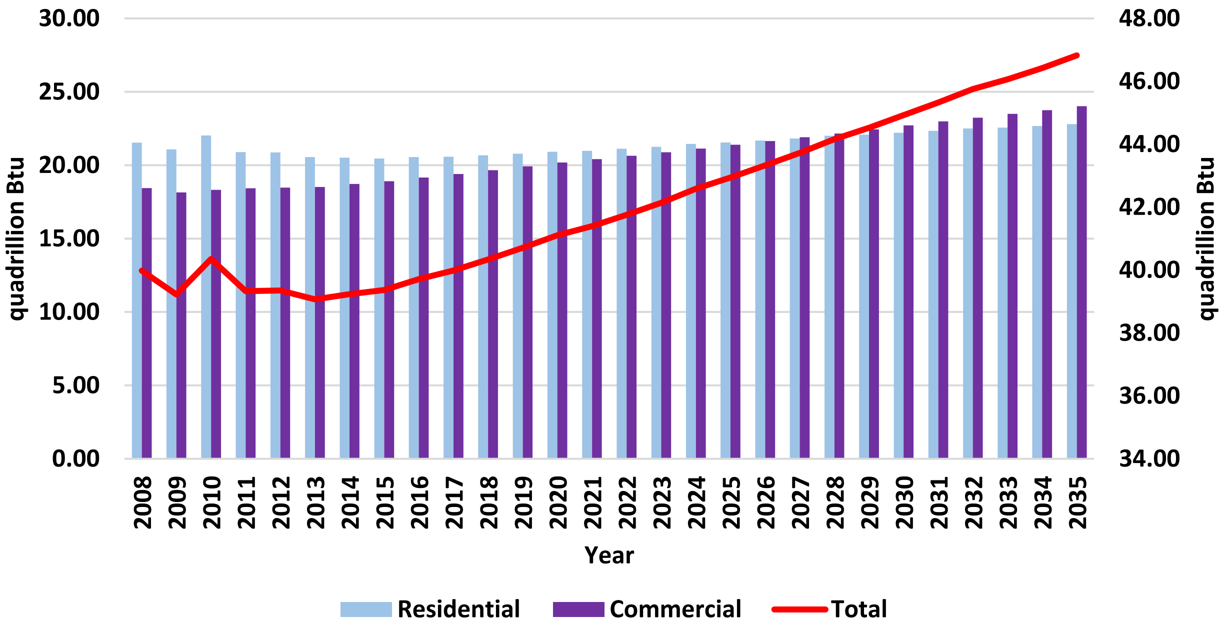

Figure 1. Building share of energy consumption [3].

On the other side, environmental impacts associated with increasing the fossil fuel consumption is another concern. Knowing that fossil fuels such as coal and natural gas will be the major fuel types contributing in electricity generation as the U.S Energy Information Administration predicted this share to reach to 65% by year 2040 [4], has increased concerns about CO_2 emitted into the air as a result of abovementioned fuel burning.

Moving toward sustainability requires minimizing the resource consumption of buildings. To achieve this goal, it is necessary to minimize the energy consumption of buildings and shift the sources of energy from non-renewable to renewable. To this end, the U.S. Department of Energy (DOE) has introduced several programs to reduce the energy usage of buildings. These plans are supposed to support the efforts to increase the energy efficiency on one side (as it is planned to reduce the energy use intensity of the U.S. buildings sector by 30% by 2030 [5]) and to boost renewable energy market penetration on the other side. Among them, Net Zero Energy Buildings (NZEB) have gained attention recently. Reaching a point where onsite electricity production can supply the whole electricity demand of the building is the goal of NZEB concept. The first step in reaching NZEB is to have an energy efficient building in the first place and then use a renewable energy source to supply the minimized energy consumption of the building.

In this regard, minimizing energy consumption should be taken into consideration alongside other constraints such as cost and comfort level of buildings. To some degree the growth in energy consumption has been countered by improvements in energy use intensity (like efficiency gain through heating, ventilation, air conditioning equipment, window and insulation, refrigeration, clothes washing ,etc.) in the past three decades such that, from 1985 to 2004, the energy intensity of the residential sector decreased by 9% although the growth in the number of households and size of houses increased total energy use [2]. More recently, the increased awareness of environmental issues associated with excessive energy use, together with increasing trend of energy demand from building sector, has lead the designers to consider energy efficiency in their design procedures and the state governments to implement tighter building energy codes [6]. The main issue in designing an energy efficient building is to identify those efficiency measures that are more effective and reliable in the long term because, with a wide variety of proposed measures, the designers have to compensate environmental, energy, and economic factors in order to reach the best possible solution that will result in maximum energy efficiency without sacrificing the satisfaction of the final users [7]. To this end, multi-objective optimization analysis seems to be inevitable to reflect the complicated interactions between various conflicting areas such as comfort level, energy use, and financial parameters.

As mentioned earlier, although increasing the energy efficiency and reaching energy efficient buildings can decrease the energy intensity, it cannot guarantee any changes in the total fossil fuel consumption trend due to a variety of parameters which affect energy consumption in the building sector such as population and building sizes. In this regard, shifting from non-renewable energy sources such as coal and natural gas (which contribute the most in supplying energy for buildings) to renewable energy sources such as solar, wind, geothermal heat pump, etc. is necessary. Renewable energy has the potential to meet demand with much smaller environmental footprints and can be helpful in other important areas such as energy security by diversifying energy sources [8]. Looking at the current trend of renewable energy consumption implies that with current technological development, the tendency toward using these kind of energies is increasing and this increasing trend is expected to continue as can be seen in Figure 2.

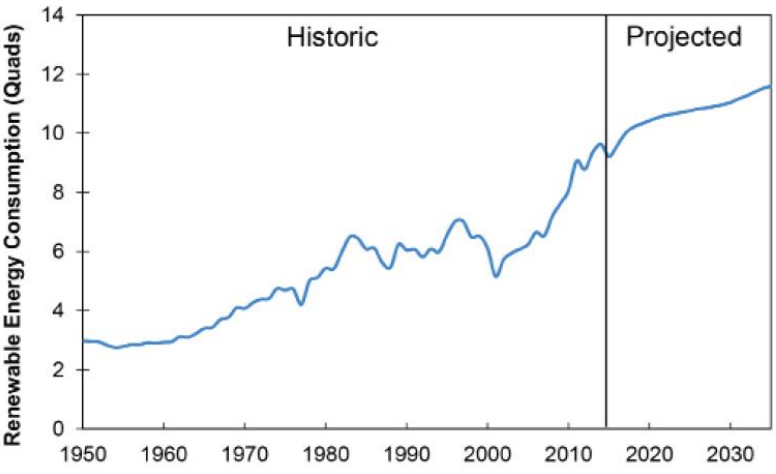

Figure 2. U.S. Renewable Energy Consumption: Historic and Projected [8,9]

Despite recent improvements, the technical potential of renewable energy sources is far higher. Modern renewable energy systems could provide all global energy services in sustainable ways [9]. Both developing a new methodology that is able to minimize the energy consumption of the building through optimizing different components that affect energy performance of buildings and integrating renewable energy sources with the main electricity supply source (grid) while considering aforementioned constraints can be great achievements in reaching a sustainable community.

In addition to renewable energy sources (solar panels, wind turbines, etc.), alternative-fuel vehicles batteries can also be considered as viable energy sources to supply the power demand of a building. Specifically, EVs have gained more attention in the past few years (see Figure 3).

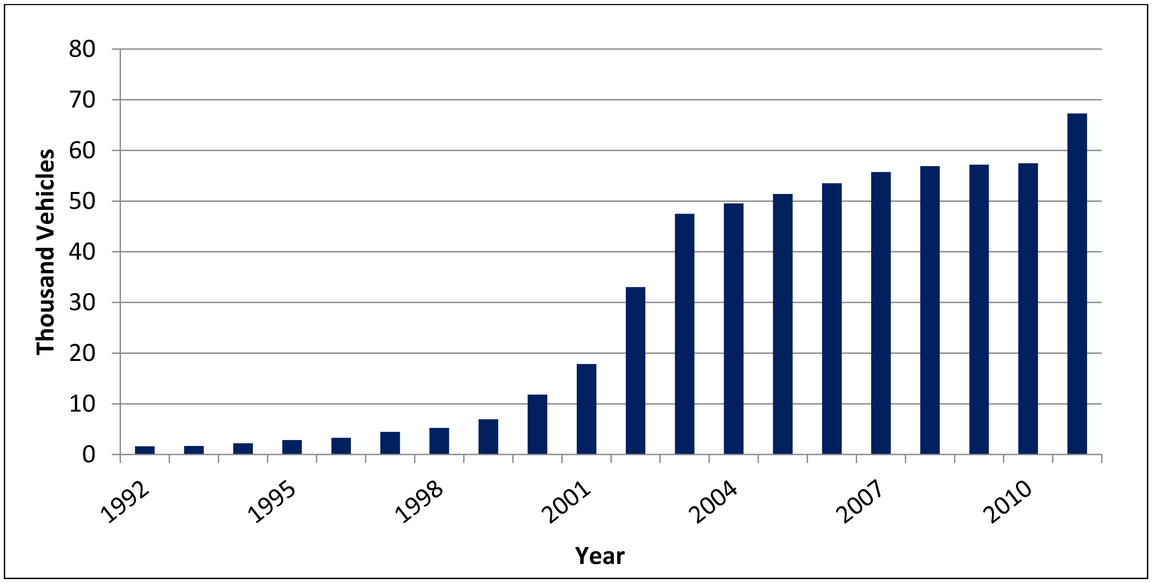

Figure 3. Alternative fuel vehicles in use in the U.S [11]

The growing market share of EVs can be seen as an opportunity to consider EV storages as a source of energy for buildings. With emerging technologies related to EVs, this type of vehicle can contribute to energy exchange with grid (V2G) and homes (V2H). The main idea is to charge EV batteries during off-peak hours when the price of electricity is lower and to deplete EV batteries during on-peak hours when the price is higher. This technology also can be considered as a reliable source of energy in the case of an emergency situation with a power outage.

Different abovementioned sources of energy for the building should interact with each other and with the grid to meet the energy demand of the building. A power distribution system should determine the energy source of the building at each specific time of the day. In this study, an algorithm is developed to connect different sources of energy together and with the grid. In this way, if the energy demand of the building is higher than that of on-site generated electricity, grid electricity can supply the shortage. On the other side, if the on-site generated electricity is more than the energy use of the building, the excess amount of electricity can be transferred to the grid. This algorithm can manage the flow of electricity from/to the building.

1.2 Aims and Objectives

The goal of this doctoral research is to investigate the design and implementation of a framework capable of designing an energy efficient building and connecting different sources of energy in buildings to reduce the reliance on grid electricity to supply the energy demand of the building.

The outreaching goal of this study is to fulfill the requirements of NZEB by:

1. Performing a comprehensive energy analysis considering different parameters affecting energy consumption of a building such as weather condition, orientation, insulation, etc.
2. Designing an energy efficient building which considers different conflicting areas such as cost, energy consumption and comfort level through performing a multi-objective optimization analysis.

3. Modeling and integrating renewable energy sources into building's energy sources.
4. Considering Vehicle to Home technology to further drive down the buildings reliance on grid electricity and consequently reduce the consumption of fossil fuel based generated electricity.
5. Developing an algorithm capable of making connections between different components of the system including grid, renewable energy source, and EV. This algorithm should be able to help in developing an effective building energy management system.
6. Developing an agent base model to investigate the dynamic interaction of different components of the NZEB system.

1.3 Research Contribution

The main contribution of this research to the body of knowledge is that it lays the foundation to explore the possibility of reaching NZEB through implementing Vehicle to Home technology (V2H) and by developing an algorithm that is able to determine the sources of energy for building at each hour of the day. This algorithm can effectively increase the capabilities of building energy management systems to supply the energy demand of buildings through energy sources other than grid electricity. This thus reduces the fossil fuel consumption and GHG emission associated with fossil fuel burning. The presented research also contributes to the building's energy consumption simulation research and practice by providing a modeling approach that, once accredited by the industry, can serve as a foundation for further work in this area.

1.4 Organization of Dissertation

To meet the defined research objectives, the dissertation is organized as follows:

1st Chapter: Introduction

This chapter will present the general information about U.S energy consumption in the building sector as compared to other sectors and the importance of reducing the ever increasing trend of energy consumption in buildings. Renewable energy usage trends and thegrowing market share of EVs are also discussed in this chapter. In addition, this chapter will include the research problem statement, aims and objectives, and organization of the dissertation.

2nd Chapter: Literature Review

This chapter describes the existing literature on DOE’s proposed plan to reduce the energy consumption in the building sector. NZEB, its definition, and its requirements are discussed in detail. Previous studies about using renewable energy sources and the abilities of these sources to contribute to the supply of the energy demand of buildings, Vehicle to Home technology, and its application are also presented in this chapter.

3rd Chapter: Methodology

This chapter explains the developed algorithm in each step and the coding procedure to apply the defined algorithm. Differences between two macro based and agent based models are also discussed in detail in this chapter.

4th Chapter: Analysis Results

The results of an energy analysis of the investigated building and an optimization analysis to reach an energy efficient building are discussed in this chapter. This chapter also involves the analysis results of the two developed models to reach a NZEB.

5th Chapter: Conclusion, Discussion, and Future Studies

In this chapter, the results of the proposed methodologies and their significance for the U.S. energy consumption in the building sector will be discussed. Then, the limitations of the study will be explained, and the conclusion of the dissertation will be made. Finally, the recommendations for future studies will be indicated.

CHAPTER TWO: LITERATURE REVIEW

In this chapter, an overview of the previous related research efforts pertinent to the presented study is provided. Also, proposed plans to reduce the energy demand of buildings, to reduce the reliance on grid electricity to supply energy demand of buildings, and to increase efficiency in building energy management systems are among the covered topics in this chapter. The foundation structure of the presented study is built upon previous developments in this field. This study is trying to develop and customize the previous research efforts in a way that can help to achieve the goals of this study.

2.1 Buildings related energy consumption and environmental impacts

The building industry is one of the most complicated and important sectors of the society [10]. The way it affects the environment, society and economy have been the topic of many types of research and debates. The efficient design approach should consider all these three main above mentioned areas at the same time when designing new buildings or retrofitting old buildings [11]. Engineering should find different ways to balance these important areas; minimizing the construction cost while increasing the comfort or increasing the productivity of people without compromising environmental impact considerations [12]. This is the general framework to show how this system should work.

Energy consumption of buildings is an essential part of investigating the environmental impact of buildings [13]. Energy consumption occurs in different phases of the building's life cycle, from construction to operation to demolition. A major part of a building's energy consumption happens during the operation phase. Consuming less energy during this use phase is highly dependent on the decisions already made in the planning and construction phase [14]. Although it is possible to modify and upgrade the building features for less energy consumption at operation phase, it will be a costly and cumbersome process effected by the occupancy type of the building.

The world's rapidly growing energy consumption rates, coupled with the associated environmental impacts of such energy consumption, has raised concerns in different communities and among researchers, engineers, and even politicians [15,16]. As buildings are responsible for more than 40% of primary energy usage and 70% of overall electricity usage in the U.S., policy-makers must quickly take action to reduce the energy demand of buildings [2]. Historical data shows that the share of U.S. primary energy consumption for buildings has increased from 33.7% in 1980 to 41.2% in 2012, and this same increasing trend is expected to continue into the future as the share in U.S. energy consumption for buildings is predicted to reach up to 42.1% in 2035 [1]. In this regard, Rising energy prices alongside with energy independence, limited resources, climate change, etc. worsen this current situation [17]. From an environmental viewpoint, the global attention to the issue of sustainability and sustainable buildings on one side and destructive role of building industry in environmental on the other side increases the demands for the design of new structures in an environmentally friendly manner and retrofit of existing structures based on environmental parameters [18]. In terms of environmental impacts, the U.S. building sector emitted 12% of the total CO_2 emissions in the U.S. in 2014 [19].

With all that being said, finding ways to reduce the energy demand of buildings and then supply it through renewable energy sources seems to be inevitable. To this end, the Department of Energy (DOE) introduced several programs to reduce the energy usage of buildings. Among them, the “Building America” program tries to bridge the gap between a high energy cost building with too much heating and cooling load (and individual rooms and floors run too hot or cold) to buildings with minimum or no energy cost that are comfortable homes smartly insulated and sealed to minimize energy usage yearlong. Healthy atmospheres that provide fresh filtered air, minimized dangerous pollutants, high quality heating and cooling systems, modern low energy, etc. are among the features of such homes[20]. There are some protocols and guidelines to design these types of buildings which discuss the detailed design procedure for different specifications of the building (insulation, duct locations, domestic hot water system, etc.)[21]. Another program developed by DOE is “home energy score,” which is aimed at providing information that helps homeowners understand their homes’ energy efficiency and how to improve it. In this program, buildings are assessed based on regional parameters such as weather data and are rated on a 10-point scale with “1” applying to homes likely to be totally energy inefficient and “10” to most energy efficient homes [22]. This program increases motivation to move toward energy efficient homes by providing the homeowners with the information about the benefits of increasing the energy score of their property. “Home performance with energy star” (HPwES) is a program introduced by the US Environmental Protection Agency (EPA) which was later expanded in partnership with US DOE in order to identify and promote energy-efficient products [23]. This voluntary labeling program has been able to work with more than 2000 certified contractors and through them complete 330000 projects in 2013 [24]. With the help of this program, 4.8 EJ of primary energy was saved and 82Tg C equivalent was avoided in 2006 year [25]. “Better buildings residential network” and “Home improvement catalyst” can also be mentioned among the programs introduced by DOE in order to reduce the energy demand of buildings. As can be seen, all abovementioned plans aimed at reducing the energy demand of buildings aremajor steps toward a sustainable community. However, in order to fully implement the concept of sustainability, new plans must be devised to integrate renewable energy sources into the energy portfolio of a building. Therefore, developing a new methodology with which to minimize the energy consumption of a building and integrating renewable energy sources with the main electricity source (the power grid) will both contribute greatly to a more sustainable community [26]. In this regard, when moving toward sustainability, it is important to not only reduce the required energy of the building in question but also to find ways to implement new and cleaner energy sources whenever possible. For this reason, shifting the building's energy sources away from the electricity grid (which tends to be the most likely source to emit air pollutants) in favor of onsite renewable energy sources seems to be inevitable. The concept of the NZEB, as explained further in the next section, has evolved primarily from this idea.

2.2 Net Zero Energy Buildings (NZEB)

There have been many debates about the definition of such homes but in 2015 DOE defined NZEB as "an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy" [27]. The goal of the NZEB concept is to reach a point where a building's onsite electricity production can supply its entire electricity demand [28].

In order to lower the energy consumption in buildings, many energy sealing techniques should be considered from the design standpoint. Low-energy consuming houses designed with such consideration are able to reduce the heating and cooling energy significantly compared with those with constructed with a conventional house design procedure. Furthermore, by applying the renewable energy system to a house that is designed to have low energy consumption, any additional energy consumption can be supplied by the energy that is produced by its own renewable energy system [29]. Leckner and Zaeureanu in a study investigate an energy efficient house that is able to use available solar technologies to generate at least as much primary energy as the house uses in a year [30]. Such housings that are able to passively save energy consumption and actively produce energy is called an energy self-sufficient housing or Net Zero Energy Building [31]. This concept has emerged as a solution to address the issue of energy consumption increases in the building sector. Many definitions have been proposed so far for a "net zero energy building," and in most cases this term refers to operation phase of the building since around 98% of the energy consumption of the building during its life cycle is consumed during this use phase [32]. In another study by Sartori et al., a framework is attempted to integrate grid power with onsite renewable energy sources such that the two power sources can interact together [28].

The NZEB concept is no longer perceived as a purely theoretical ideal for future applications, but as a realistic and achievable goal to reduce buildings' energy consumption levels and to subsequently mitigate CO_2 emissions from the building sector [33]. Growing attention to the NZEB concept can be seen in a number of buildings constructed based on this theory as practical examples thereof [34–37]. The Energy Independence and Security Act (EISA) of 2007 has set Initiative to support the goal of net zero energy consumption for all new commercial buildings by 2030, and to extend this goal to reach a net-zero-energy target for 50% of U.S. commercial buildings by 2040 and for all U.S. commercial buildings by 2050 [38]. The Energy Performance of Buildings Directive (EPBD), published in 2002, obliged all EU countries to enhance their buildings' regulations and to introduce energy certification schemes for buildings [39]. To this end, the EPBD Directive of 2010 has set a target of "nearly zero energy buildings" by 2018 for all public buildings and by 2020 for all new buildings [40]. As can be seen from these goals, the international community now regards the NZEB concept as a viable solution to the increasing energy consumption levels and CO_2 emissions of today's buildings.

Across all definitions and classifications for the NZEB, one basic design rule remains constant; tackle demand first, and then supply [38]. As can be seen in the definition, the first step to reach NZEB, is to minimize energy consumption of buildings as much as possible considering other factors such as cost or comfort level. Based on DOE, Zero Energy Ready Homes have to be at least 40% to 50% more energy-efficient than a typical new home built in the same year [41]. This definition is more clearly visualized in Figure 4 below, where a rough comparison is shown between the energy consumption levels of a typical code compliant building, a more energy-efficient building, and a NZEB. The process of designing an energy efficient building is further explained in next section.

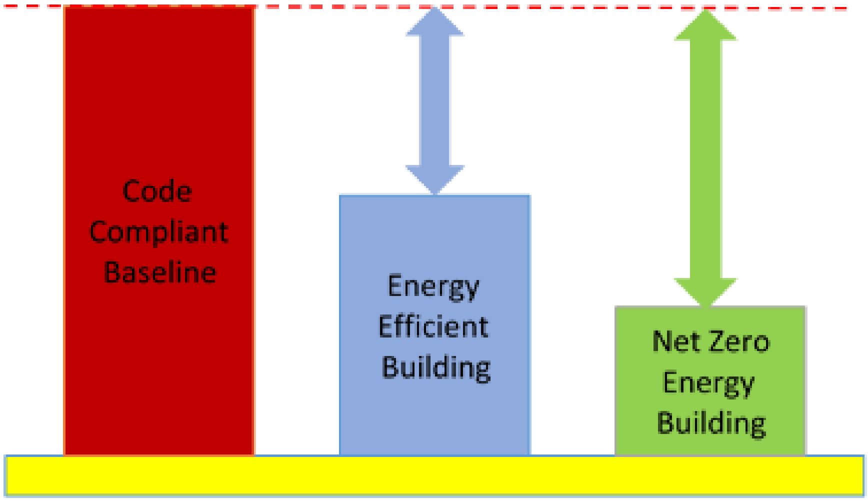

Figure 4. Energy consumption comparison for different types of buildings

2.3 Energy Efficiency (EE) in buildings

Reducing energy consumption and consequently CO_2 emission in the building sector is the primary goal of performing energy performance analysis [42]. In this regard, government incentives and supports for improving energy efficiency seems to be a linchpin. A vast network of research continually develops innovative, cost-effective energy saving methods and introduces better products to minimize the energy consumption of buildings[43–45]. Energy efficient buildings are designed to save money, support the economy of the country and reduce pollution [46]. The improvements in building energy efficiency will help the nation achieve its goal of reducing energy-related greenhouse gas emission 17% by 2020 [47]. Moreover, more than $400 billion is spent annually to power homes and commercial buildings while much of this money usually wasted due to inefficient energy performance design of buildings, according to U.S Department of Energy [47]. Cutting the wasted energy usage will save almost $20 billion annually, which will be helpful in creating more jobs and strengthening the economy of the country. Having an energy efficient building may increase the upfront cost, but these additional costs will be compensated by lower energy bills during the operational phase of the building. On a family scale based on $2000 per year energy bill of an average American family, a $400 savings can be anticipated as a result of upgrading the building with energy efficient products [47].

As discussed earlier, moving toward sustainability requires minimizing the resource consumption of buildings, meaning that the energy performance of buildings should be maximized without sacrificing their comfort levels [48,49]. To design energy-efficient buildings, several studies are available that have investigated factors such as thermal insulation and building envelope, age, size, lighting and lighting control systems, outdoor weather conditions, HVAC equipment, building orientation, urban texture, and other applicable factors in an effort to reduce the energy consumption of a particular building [50–53]. Among these is a study by Balaras et al., who investigated the effect of a building's thermal insulation (including floor, window, wall, and roof insulation) on the energy performance of the building [54]. Other studies investigated the potential of smart occupancy sensors to reduce a building's energy consumption [55–57]. Note that these sensors should be able to deliver the information with an energy-efficient routing algorithm that does not rely on GPS information so that it can work inside home [58,59]. In addition, since HVAC system management is another major concern when designing an energy-efficient building, some studies have specifically investigated the influence of HVAC system management on the energy consumption of buildings [60–62].

Most of the abovementioned studies have focused on specific aspects of a typical building's energy consumption, and have tried to simulate and analyze the effect of those specific components on the energy demand of such a building. However, since one of the goals of this study is to design an energy-efficient building, it is therefore necessary to simultaneously consider all of the most important factors affecting a building's energy consumption in an optimization analysis to select the best design alternatives. In this regard, it is necessary to optimize the parameters that influence the energy and investment costs and the thermal comfort of such a building (envelope, HVAC, etc.) [63]. However, achieving this goal requires a thorough study to find better design alternatives that satisfy a variety of conflicting criteria, such as those pertaining to economic and environmental performance [64], so as to help designers overcome the drawbacks of trial-and-error with simulation alone.

There are several studies in available literature on optimization approaches and their suitability for minimizing a building's energy consumption [65]. For instance, Fesanghary et al. investigated the application of a multi-objective optimization model based on a harmony search algorithm to find an optimal building envelope design to minimize life cycle costs and emissions [66]. In addition, Hamdy et al. proposed a modified multi-objective optimization approach based on a Genetic Algorithm to design a low-emission, cost-effective dwelling [67]. It has also been noted that minimizing energy consumption should be taken into consideration along with other constraints such as costs and the comfort levels within buildings [68]. Therefore, this study uses an optimization approach through the use of a built-in optimization tool developed by Designbuilder [69]. With this optimization tool, it is possible to identify different design alternatives with various combinations of costs, energy consumption rates, and comfort levels, using the Genetic Algorithm (GA) method to perform a multi-objective optimization analysis. After reducing energy demand to a reasonable level, the next step in achieving a NZEB is to concentrate on the onsite energy supply of the building which is discussed in next section.

2.4 Renewable Energy Systems

Different methods to reduce the energy consumption of buildings have already been discussed in previous sections, and, in this section, the main focus is on energy supply. As the concerns over the increasing trend of fossil fuel consumption in the U.S is rising, many efforts have been implemented to replace the energy derived from fossil fuel with renewable energy sources such as wind, solar, geothermal, biodiesel, ethanol, etc. In this regard, as a result of the U.S. Environmental Protection Agency's Clean Power Plan (CPP), a greater energy efficiency and a shift from coal-fired electricity generation to a combination of higher natural gas-fired and renewable generation are expected [70]. Even without this abovementioned plan, due to Congress's recent extension of a favorable tax treatment for renewable energy sources, it is expected to see a significant growth in the renewable generation of energy throughout the country such that EIA projects an annual average increasing rate of 3.9% in renewable energy generation, while natural gas generation will grow at 0.6% per year where the CPP is never implemented from 2015 to 2030[70].

As can be seen in Figure 5, the total renewable energy production has increased significantly from 2973 trillion Btu in 1949 to 9574 trillion Btu in 2015.

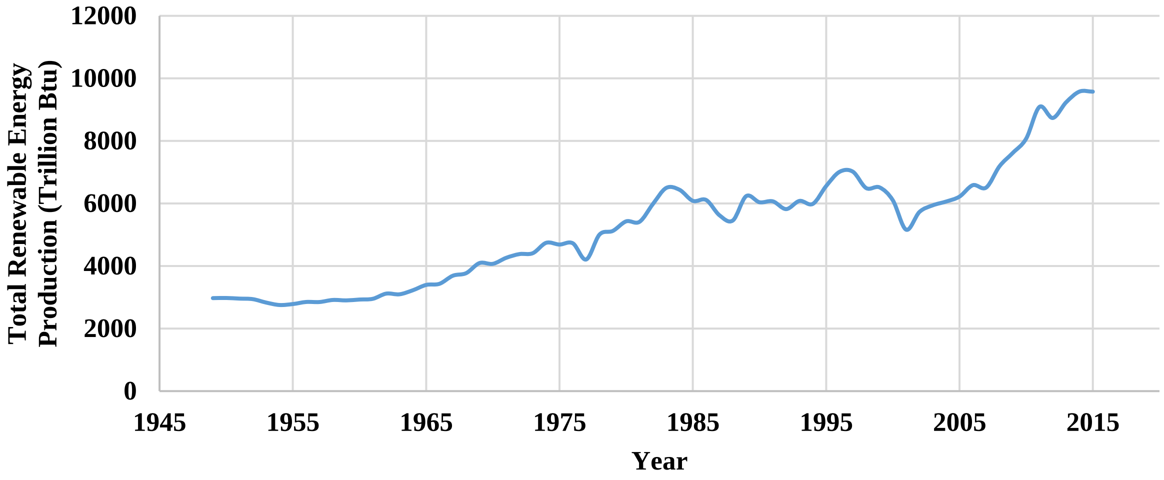

Figure 5. Total Renewable energy production in the U.S [71]

The sun has produced energy for billions of years, and the energy in the sun's rays as they reach the earth can be converted into electricity through Photovoltaic (PV) cells, often better known as solar cells [72]. Solar energy is no longer viewed as a minor contributor to the nationwide energy grid mixture of the U.S., as it used to be in previous years due to high costs and other practical constraints [73]. Photovoltaic (PV) systems are like any other electrical power generation system, with some differences in the equipment used as opposed to the standard equipment for conventional electromechanical generation systems [74]. A basic diagram of PV systems is presented in Figure 6 below. In order to convert solar energy to base-load power, excess power produced during sunny hours must be stored for use during nighttime (on-peak) hours [73].

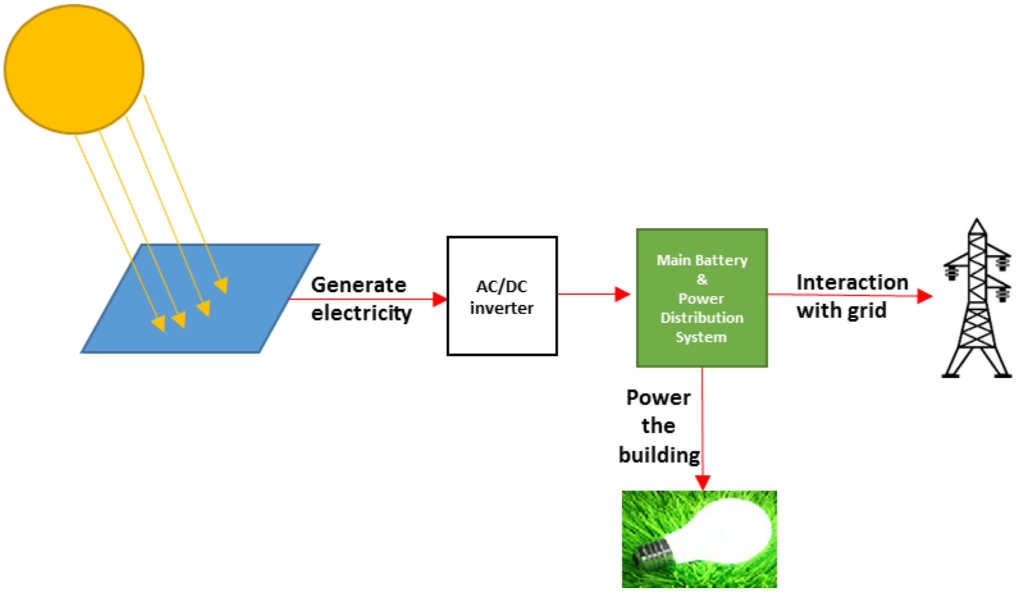

Figure 6. PV System Components

New types of renewable energy sources should be employed for a NZEB, and in this regard, many studies have investigated the use of various renewable energy sources (solar panels, wind turbines, geothermal heat pumps, etc.) to supply the energy demand of buildings. For example, Charron investigated the use of thermal and solar photovoltaic (PV) technologies to generate as much energy as a typical home would need on annual basis, in what can be referred as a net zero energy solar home [75]. The life cycle costs of such homes is also an important topic to discuss, and has been investigated in different studies [30]. Another study by Iqbal investigated the feasibility of using wind energy in a net-zero-energy home, taking into account critical parameters such as wind speed [76]. Some studies have even tried to combine different types of renewable energy sources to design a NZEB. For instance, Melissa et al. investigated the power generated through solar thermal energy and wind power to supply the energy demand of a building [77], while Noori et al. investigated the socio-economic and environmental impacts of producing electricity for buildings using wind power plants [78]. Small hydropower plants located across high slope terrines in the upstream parts of river networks [1] have been utilized to provide energy for buildings and small communities in developing countries [79]. However, this energy source is less reliable, compared to wind or solar energy, due to the high temporal variation of flow and channel extent [80] as well as its geographical limitations.

Despite all of the progress have made in recent years, efforts still are continuing to introduce new systems that can help in reducing the energy consumption of the building. Using newer technologies to increase the production of more renewable energy with the lower price is one of the major concerns toward reaching NZEB [81]. One of the deficiencies in this field is the lack of a holistic picture of the problem and its solutions. Concentrating on a building itself and ignoring the surrounding environment and technologies may lead to an infeasible solution or feasible, but unreasonable solution when considering other determining parameters such as cost. In this regard, ignoring the role of vehicles in reaching NZEB can be considered as a weak point. Knowing that 95% of American households own a car [82], highlights the fact that house and vehicle should be coupled and be seen as one complex when designing to reach NZEB [83]. Vehicles can play a very important role in supplying part of the energy demand of buildings.

The role of vehicles in supplying the energy demand of buildings is now yet another possibility to be investigated. With the help of newly introduced technologies, it is possible to use vehicles (esp. household vehicles) as potential energy sources for buildings. These technologies and their applications are discussed in further detail in the next section.

2.5 Vehicle to Home (V2H) Technology

In this study, the employment of new technologies to supply the energy demand of the building such as solar panels, wind turbine, and alternative fuel vehicles will be tried. In this way, the building is not a separated subject; rather, vehicular energy and other sources of renewable energies along with the home now will be considered as a single complex that needs to be considered simultaneously [84]. In addition to renewable energy sources (solar panels, wind turbines, etc.), alternative-fuel vehicles can also be considered as viable energy sources to supply the power demand of a building. The idea is that an electric car is essentially a rolling pack of giant batteries, and it could be used as any other battery would be used [85]. But instead of connecting up thousands of Duracells, your car can talk with the power grid, its charging station, and the house to know when and how much electricity is needed [86]. Officially called Vehicle to Home or V2H, this concept extends beyond simply providing emergency backup power [87,88].

Currently, 95% of American households own a car. Due to growing concerns over conventional and unconventional air emissions as well as future oil supplies, government officials have set different goals to increase the market share of EVs as zero-emission alternatives to gasoline powered vehicles [89]. In the U.S., there are medium-term goals where EVs would consist of 20% of the passenger vehicle fleet (approximately 30 million EVs) by 2030 [90]. Current market share projections for EVs in the U.S. show that, with sufficient government support, the market share of EVs (in terms of new sales) could reach up to 26% by 2030 [91]. As EVs are being adopted at an accelerating rate, attentions toward the concepts of Vehicle to Grid (V2G), Vehicle to Home (V2H), and Vehicle to Vehicle (V2V) technologies are also increasing. Existing bi-directional charging technology allows intelligent charging to be taken to a new level; with the help aforementioned technologies, the use of EVs can be considered an opportunity to use EV networks as power sources in and of themselves [92].

Figure 7 shows a schematic view of how EVs can be coupled with the building in order to transmit the power from vehicle to building. Due to great flexibility of the interaction of EVs and plug-in hybrid electric vehicles (PHEVs) with the power grid, these vehicles will play a significant role in the future of the power system [93]. On the large scale, an organized fleet of EVs can be considered as a reliable, flexible power store for a set of building blocks. In smaller scales, individual EV owners can use their own EVs as a source of power alongside with other sources of power [94]. This technology has already started to be used by some car companies such as Nissan as implemented in Japan [95].

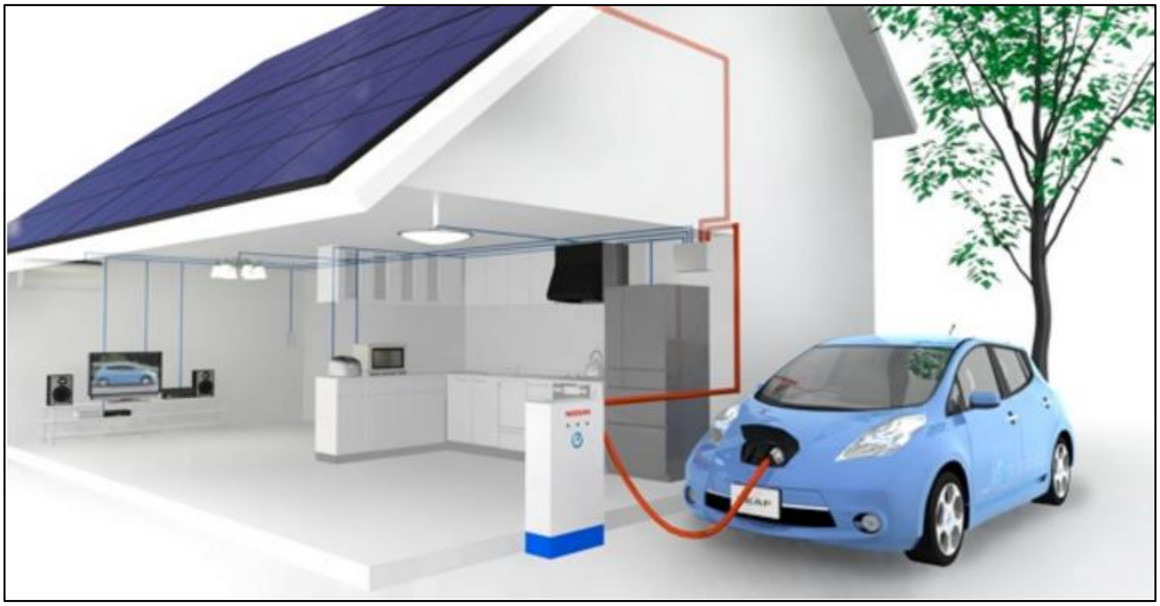

Figure 7. Power transmission from EV to building [72]

There have been an extensive amount of research studies on V2G technology, including studies on its feasibility, applications, limitations, and so on [96–102]. Different studies in this regard have examined this technology from different perspectives. One such study by Haines et al. developed a simple V2H model for a home's daily energy demand [92]. Another study by Liu et al. introduced different methodologies for using V2H, V2G, and vehicle-to-vehicle (V2V) technologies [103]. Cvetkovic et al. presented a small grid-interactive distributed energy resource system consisting of photovoltaic sources, plug-in hybrid electric vehicles (PHEVs), and various local loads [104]. Moreover, Noori et al. investigated the regional net revenue and emission savings that may be possible with the use of V2G technology [105]. The life cycle cost (LCC), environmental impacts, and market penetration of EVs are also important areas to consider when performing a thorough life cycle analysis of the system as a whole [106,107].

V2H technology is a newly introduced type of system with the same concept as that of V2G technology, allowing individuals to supply the power demand in their homes with the energy stored in EV batteries. Since the electricity withdrawn from EVs alone is not enough to take a home off of grid electricity completely, V2H technology used to be considered mainly as a source of backup power during emergency situations or blackouts. It is estimated that, in 2011, the average duration of power outages in the U.S. had been 222 minutes with 20,109 people affected on average as a result of such events [108]. EV batteries are also beneficial for integrating renewable sources into a building's energy supply system in that they can help to minimize fluctuations in generated onsite electricity. Another advantage of adopting V2H technology is the potential reductions in the electricity bill for the building by storing electricity during off-peak hours and then reducing grid reliance by depleting the EV battery during on-peak hours. As discussed earlier in the definition of a NZEB, the onsite or offsite renewable energy sources should supply the yearly energy usage of the building. Using this technology in conjunction with other renewable energy sources makes the overall system more energy-efficient by storing excess energy generation during off-peak hours for use whenever the available power generation is not sufficient to meet the energy demand.

V2H technology enables users to connect a variable number of vehicles to a building's power distribution board, making it possible to supply the building's power demand at nighttime (when the building's electricity usage is usually at its peak). This is accomplished by depleting the stored power in the batteries of EVs and then charging the battery when the power demand is low, using electricity from the power grid or from other renewable energy sources (solar panels, wind turbines, etc.). From the consumer's viewpoint, this means that cars are usable for mobile energy storage and not just for transportation purposes, being able to provide power to a building and thereby alleviate the corresponding stress on the conventional power grid. A schematic of the overall concept considered in this study is shown in Figure 8 below.

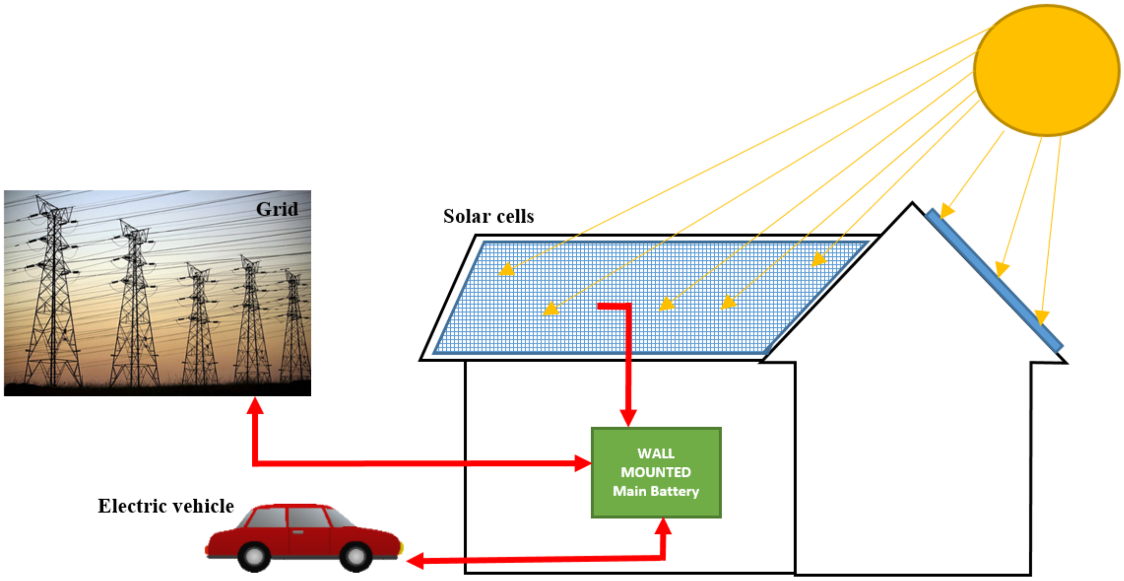

Figure 8. Net Zero Energy Building [86].

2.6 Agent Based Modeling (ABM)

Unlike continuous simulation approaches, ABM is a discrete-event simulation method that is suitable in situations where variable change in discrete times and events are in discrete steps [109]. Agent-based modeling is a simulation method that investigates the interactions between different agents through creating a virtual environment [91]. Axtell defines ABM as a combination of "*individual agents, commonly implemented in software as objects. Agent objects have states and rules of behavior. Running such a model simply amounts to instantiating an agent population, letting the agents interacts, and monitoring what happens*" [110].

For the purpose of this study, an algorithm is developed using agent based modeling to incorporate solar energy along with an EV battery to supply the energy demand of a building. The agent-based model simulates the interactions between all of the active agents in the system and evaluates the energy savings and economic benefits of different building designs. This model builds a test bed in which the owners and decision makers can instantly see the economic and environmental differences between design variations.

CHAPTER THREE: METHODOLOGY

This chapter discusses developed methodologies to reach NZEB in two systems. The general methodology of this study is illustrated in Figure 9 below, which summarizes the different steps taken in this research to achieve a completed NZEB design. These steps are described in detail in the following sections.

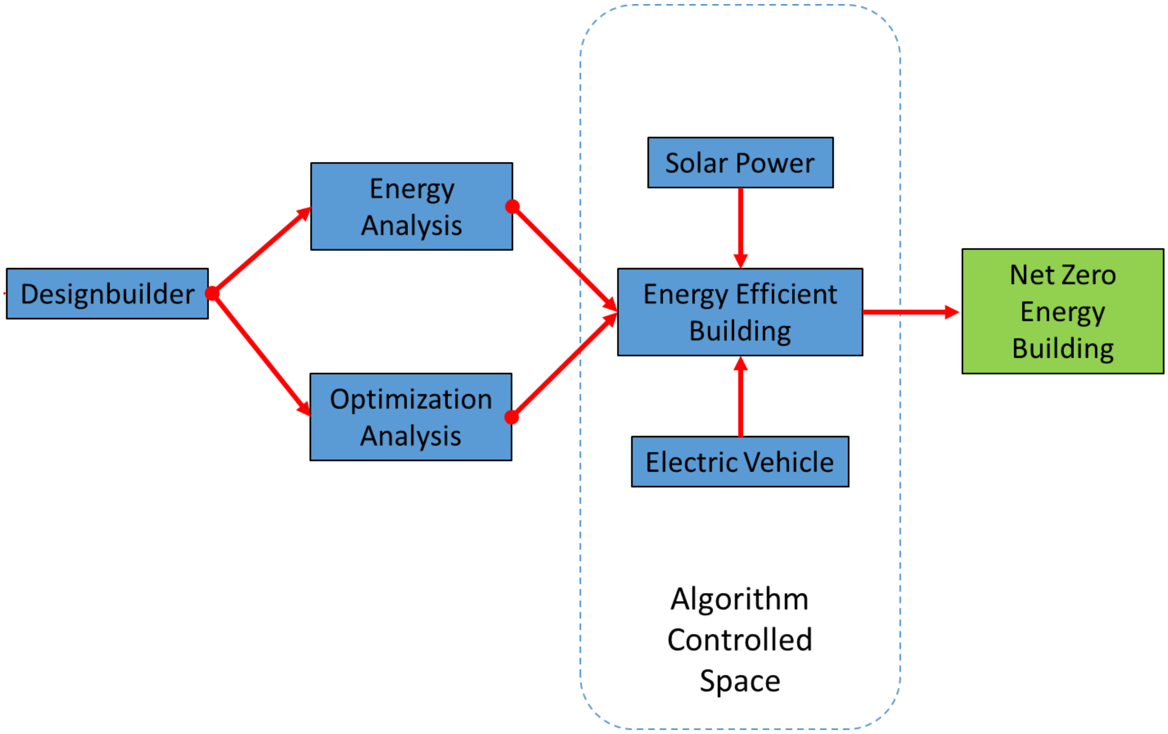

Figure 9. Developed Methodology [111]

As shown in Figure 9, the overall process for two systems starts with modeling the building itself. The difference of two systems is in the way governing algorithm works. The first algorithm (NZEB-VBA) initially developed to help the whole system to move toward reducing the reliance on grid electricity by providing a platform where different components of the system (such as EV battery, main battery, grid electricity, etc.) can interact with each other. Tracking the behavior of the components was not originally the main area of concern. After importing the results of the energy analysis, the developed algorithm can calculate the values of different important parameters such as required electricity from grid, transferred electricity to the grid, the cost of electricity throughout the year, etc., instantly after running the model. Although this model can generate the results in a very short time, it lacks the ability to track the behavior of different components of the system and instead gives the final analysis results instantaneously. This model was a firm basis to develop another model that is able to investigate the dynamic interaction of the system's components throughout the year. The role of an on-line interactive energy consumption information system to reduce the energy demand of buildings is proven [112,113]. Since most of energy initiatives are one-time upgrades that are not measurable over time, the benefits are these improvements are soon lost [113]. In order for a system to be viable, it is important to represent the benefits and advantageous over time. For a complex system of a building with different sources of energy including grid electricity, EV battery storage, and solar panels; this information can be vital when considering EV-NZEB as a worthwhile option. The second model (NZEB-ABM) enables decision makers or homeowners to see the value of aforementioned components in every hour of the day. With all that being said, from now on, two sub-sections 3 and 3.2, describe the procedure to develop two algorithms.

3.1 NZEB-VBA model development

The general methodology of this model is illustrated in Figure 9 above, which summarizes the different steps taken in this research to achieve a completed NZEB design. These steps are described in detail in the following sections. As shown in Figure 10, the overall process starts with modeling the building itself, followed by an energy analysis and an optimization analysis in order to design an energy efficient building. Next, solar power and an EV battery are integrated in conjunction with the main energy source of the designed building (grid electricity), and the resulting interactions within this system as a whole are controlled using an algorithm introduced in the following sections.

3.1.1 Modeling procedure

For modeling purposes, the building modeled in this study is a two story residential building with a total area of 1,184 square feet and a net conditioned building area of 1,074 square feet. This model can be seen in Figure 10. The detailed specifications of the modeled building are summarized in Table 1.

Table 1. Modeled Building's Specifications

Parameters	**Values and types**
Gross Wall Area	1,239 sq ft [115 sq m]
Window Opening Area	295 sq ft [27.4 sq m]
Gross Window-Wall Ratio[%]	23.80
Gross Roof Area	632.60 sq ft [58.77 sq m]
Skylight Area	50.30 sq ft [4.67 sq m]
Skylight-Roof Ratio [%]	7.95
Weather File	Orlando Sanford Airport FL USA TMY3 WMO#=722057
Latitude [deg]	28.78
Longitude [deg]	-81.3
HVAC system	Ground Source Heat Pump (GSHP)
Lighting system	Fluorescent, Compact (CFL)

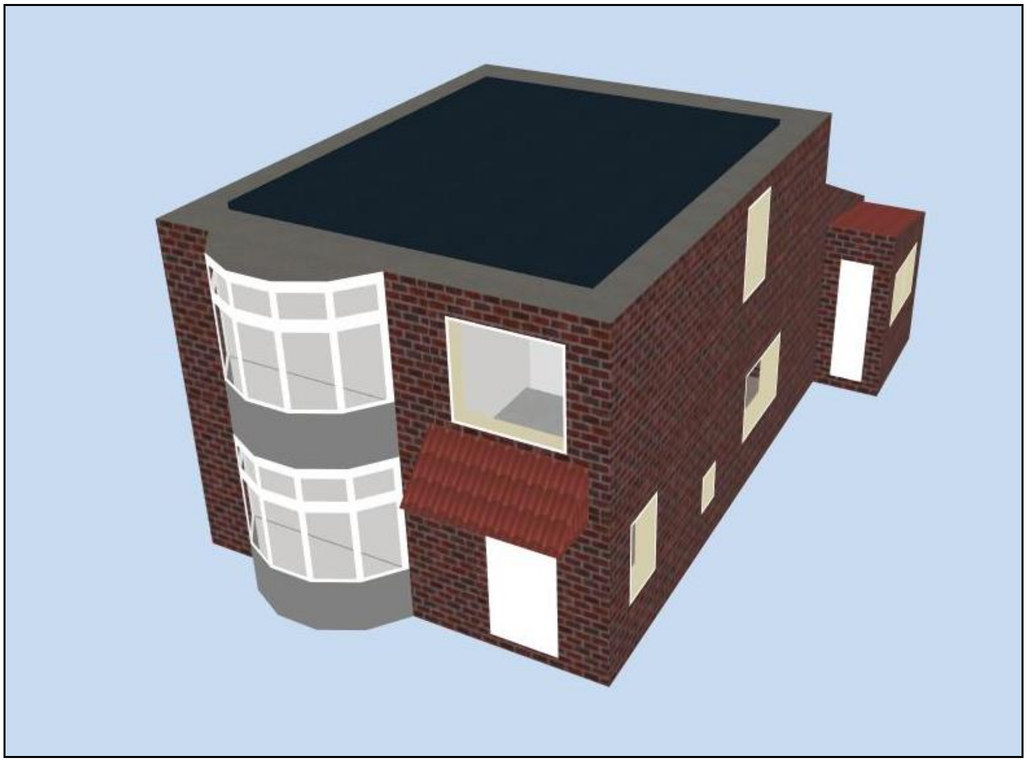

Figure 10. Developed Model in Designbuilder

In the next step, the developed model is used to evaluate the energy performance of the building. The Department of Energy (DOE) recommends a complex variety of tools and software for different design purposes, and one of the most comprehensive software programs currently available is EnergyPlus, which is designed to simulate and assess the energy consumption of the entire building [114]. Architects, engineers, and researchers have been able to use EnergyPlus to model the energy consumption of a designed building, (including energy consumption from heating, cooling, ventilation, lighting, and water usage) while also providing users with a broad range of alternatives for each component [115]. However, EnergyPlus reads inputs and writes outputs to text files, which can make it somewhat difficult and time-consuming to work with. In order to increase the usability of this software and make it more understandable for ordinary engineers, several graphical interfaces for EnergyPlus have been introduced. The graphical interface for EnergyPlus used in this study is Designbuilder, which accounts for the weather conditions of a particular region when performing an energy performance analysis, allowing the analysis in this study to account for average annual sunshine, wind speed, temperature, and all weather-related situations in addition to the other factors previously discussed [116]. An example of this consideration can be seen in Figure 11 where solar irradiation of a region is considered when analyzing the energy performance of the building.

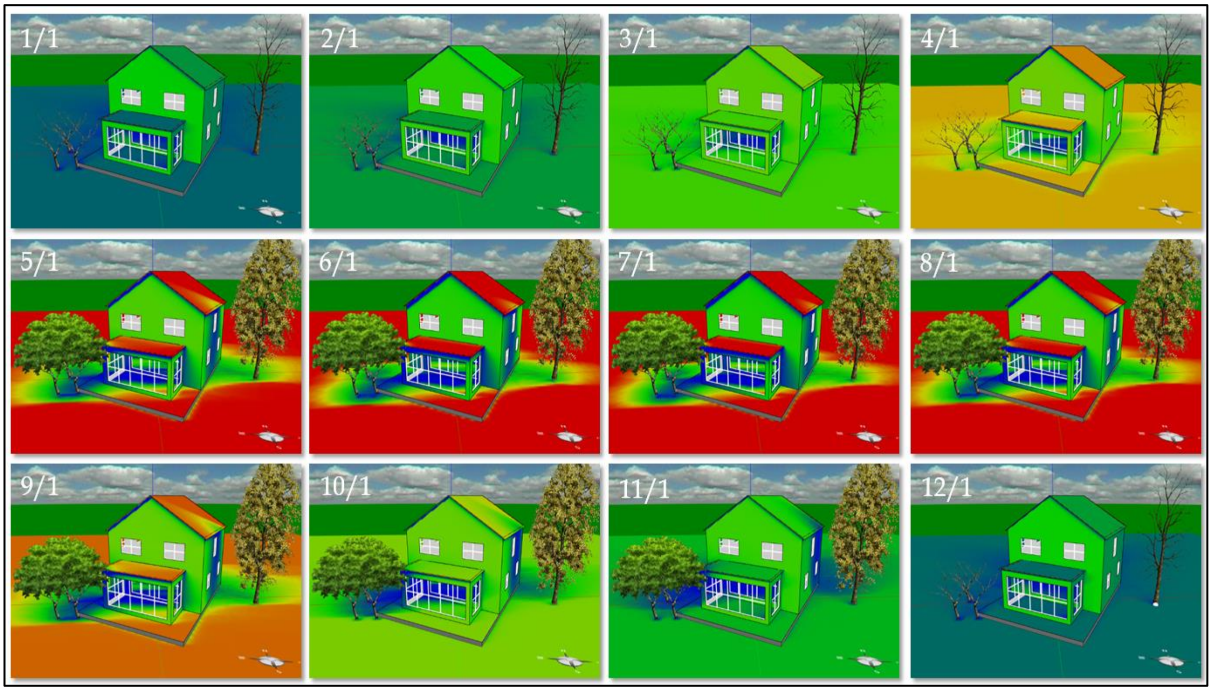

Figure 11. Twelve-month solar irradiation heat maps of a house (location: Boston, MA) [117]

3.1.2 Optimization of the Building's Energy Performance

Once the model is defined and the applicable weather database file is imported, the next step is to analyze the building's energy performance. As mentioned earlier, the process of choosing the best design options is a time-consuming process that requires a powerful database to enable designers to choose the best design alternative, while also considering relevant design constraints during the search for an optimal solution. Regarding the energy performance of a building, many different factors should be considered simultaneously in order to find an optimal solution; for purposes of this study, an optimal design should provide a high-quality, comfortable building fully compliant with the applicable standards and codes while also reducing the initial cost, operational energy usage, and environmental impacts of the building [118]. In this regard, an optimization analysis is performed in order to select the best building design options with which to minimize the energy consumption of the building in question without compromising any more than necessary in terms of cost, environmental impacts, or (more importantly) the comfort of the residents.

The process of finding the best design alternatives can be very difficult, especially with respect to conflict areas such as those related to economic and environmental performance levels [119]. The method used for this purpose should be chosen in a way that allows for a multi-objective optimization and also works relatively well given the non-explicit nature of the applicable objective functions [120]. Designbuilder provides a user-friendly interface that enables engineers to compare a set of different alternative design options for building envelopes (wall insulation, glazing type, etc.) as well as different heating and cooling systems, using the Genetic Algorithm

(GA) multi-objective optimization method to select the best design alternatives. It is worth mentioning, however, that the Genetic Algorithm method does not guarantee the optimal solution, but instead finds an approximate solution to the optimization problem [42,43].

In this regard, more than 66% of the energy consumption of residential buildings is related to HVAC and lighting systems [2]. In this specific case study, considering the weather conditions in Orlando, cooling and lighting loads are expected to have dominant shares in the overall energy consumption of the building, which would match with the preliminary results of the energy analysis of the building in question. Therefore, in order to optimize the energy consumption of the building, more emphasis is placed on testing different HVAC and lighting systems to find an optimal solution that reduces energy consumption as much as possible. Figure 12 shows the results of this optimization analysis with different design variables and objective functions. In this figure, the results of the GA optimization method are shown as a set of optimal solutions, but the best design method with the least amount of energy consumption and the lowest cost can still be derived as a result of the aforementioned optimization analysis.

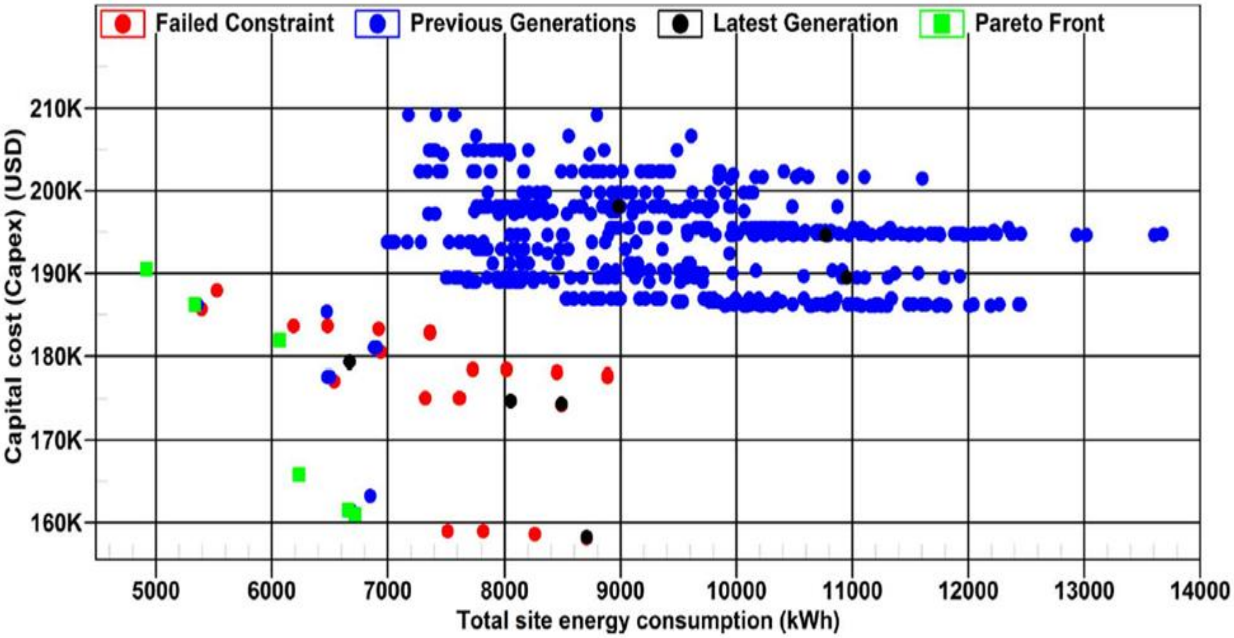

Figure 12. Optimization Analysis Results

As seen in Figure 12, a set of different colorful points is illustrated in this graph, with each point representing a separate design method with different HVAC and lighting systems. In general, three main areas must be considered when optimizing the energy consumption of the building: total site energy consumption, capital cost, and comfort level. For this purpose, the parameter values of the optimization analysis are set in a way that minimize the capital cost and total onsite energy consumption of the building. Clearly, as the system becomes more efficient, the energy consumption of the building decreases, but the capital cost may increase. On the other hand, ASHRAE Standard 55-2013 states that, for thermal comfort, the temperature in the building may range between 67°F and 82°F (approximately 19°C and 27°C, respectively) [122]. In order to ensure an acceptable level of comfort in the building, the comfort level is considered as a constraint in the optimization analysis, meaning that the only acceptable design methods are those that can ensure a comfortable temperature within the specified ranges; the green points in Figure 12 indicate the solutions corresponding to these designs. The red points represent the design methods that are optimal in terms of both capital cost and energy consumption, but fail to provide the desired comfort level. Based on recommended temperatures by DOE, the indoor temperature was set on 68°F for winter time and 78°F for summer time [123].

During the optimization analysis, approximately 1,990 design set points were tested, and based on the results, 6 of these points are found to be acceptable for consideration as the optimal design methods. The specifications and optimization results for these 6 designs are summarized in Table 2.

Table 2. Optimization Analysis Iterations

HVAC template	Lighting template	Cooling system (COP)	Onsite energy consumption (kWh)	Capital cost (Capex) (USD)	Comfort Temp (°C) in building
Air to Water Heat Pump (ASHP), Convectors, Nat Vent	T8 Fluorescent - triphosphor - with STEPPED dimming daylighting control	2.6334	5,336	186,203	27.75
Natural ventilation - No Heating/Cooling	T8 Fluorescent - triphosphor - with STEPPED dimming daylighting control	3.5757	6,659	161,514	27.69
Natural ventilation - No Heating/Cooling	T8 (25mm diam) Fluorescent - triphosphor - with ON/OFF dimming daylighting control	3.3157	6,719	170,000	27.71
Electric Convectors, Nat Vent	LED with linear control	2.7624	6,069	181,917	27.6
Air to Water Heat Pump (ASHP), Convectors, Nat Vent	LED with linear control	2.6862	4,918	190,489	27.6
Natural ventilation - No Heating/Cooling	LED with linear control	3.1202	6,235	165,800	27.54

The above table describes the most optimal design points, such that their respective capital costs and energy consumption levels are both optimized while also ensuring that the basic requirements in terms of thermal comfort are met. In order to select the most efficient system among these 6 designs, the results of a separate energy analysis have first been derived for each design. Afterward, by comparing the discomfort hours of different systems based on ASHRAE 55-2004, the system with the lowest amount of total discomfort hours has been selected as the final optimal design. Now, after reducing the energy consumption of the building, the next step is to devise a system with which to supply the required power to the building.

3.1.3 Power Supply System

In the following two sections, each of the energy sources chosen for the hypothetical building in this research (solar power and EV) are described in further detail.

3.1.3.1 Solar Power

In this study, in order to consider solar energy as a part of a power supply system, a series of solar panels with a total area of 108 square feet is modeled on the roof of the building, as indicated by the dark blue areas in Figure 13, and each solar panel works as a separate electricity generator. The modeled solar panels generate DC electricity, which must be converted to AC electricity so that the generated power can be used for the building’s appliances and stored in a battery designed to store AC power, which is the most widely available battery type for consumers. In short, the operation scheme of the solar panels is designed to generate electricity regardless of the energy demand at any particular time, while any excess amount of this generated electricity can be transferred to an EV battery and then stored in the main battery.

In this study, the solar panels are placed on top of the roof of the building in order to simulate the worst-case scenario in which the building in question is surrounded by other buildings, although it must be noted that, in many cases, it is possible to use the backyard and/or the front yard of the building to install these panels and generate electricity. The amount of solar energy generated with the solar panels depends on the properties of the modeled solar panels; detailed specifications for the solar panels in this study are presented in Table 3.

Table 3. Solar Panel Characteristics

Parameter	**Characteristics**
Solar collector type	Photovoltaic
Performance type	Simple
Performance model	PV with constant efficiency of 0.15
Heat transfer integration mode	Decoupled
Material	Bitumen felt
Area	108 sq ft [10 sq m]

In order to integrate defined solar panels into the building's energy supply system, "electric load centres" are used. This energy distribution system can include all on-site electricity generators such as solar panels and wind turbines in a simulation. The generators should be dispatched according to operation schemes and track and report the amount of generated electricity.

The operation scheme for electricity generators can be "base load, demand limit, track electrical and track schedule". In demand limit operation scheme, purchased electricity from the utility is limited to a specified amount. In track electrical operation scheme, it will be tried to have the generators meet all of the electrical demand for the building. Track schedule operation scheme works in the same way as track electrical operation scheme but the generators follow the determined schedule to meet the electrical demand of the building. In this study, the operation scheme is set to be “Base Load” which requires all available generators to operate even if the amount of generated electric power is more than the total facility electric power demand. In this case, the surplus generated electricity can be stored in electric storage or transferred to the grid.

Moreover, the amount of generated solar energy depends on the time of day, the amount of incoming solar radiation, and the angle of the solar panels with respect to the sun. All of these parameters have been considered when analyzing the solar power generation for the building. In order to better understand the way that the modeled system interacts with the position of the sun, a schematic view of the analysis is shown in Figure 13. In the example illustrated in the figure, the position of the sun (sun-path diagram) is shown for July 15th at 11 A.M.

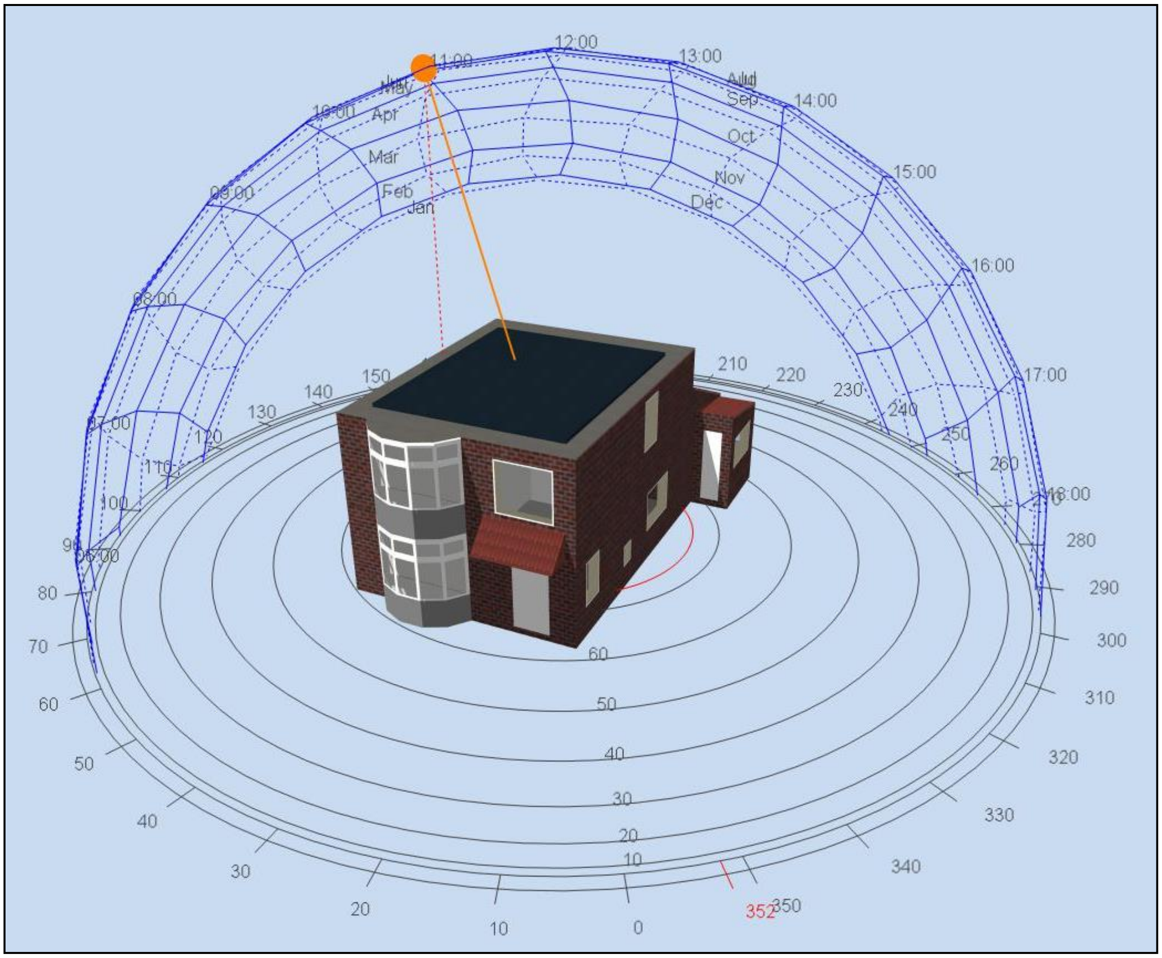

Figure 13. Schematic View of Sun-Path Diagram

Cost-related issues pertaining solely to solar power are beyond the scope of this study, and are not included in the results because the results can vary significantly depending on the boundaries of the cost analysis, and so a separate study is needed to fully investigate costs specific to solar electricity. That said, it is worth mentioning that the production price of solar energy has continuously decreased over the past few years, having dropped from 21.4 cents/kWh in 2010 to 11.2 cents/kWh in 2013 [124]. In order to make solar power more cost-competitive with traditional energy sources, a target has been set to reduce this price to 6 cents/kWh, which is now an achievable target given the current decreasing trend in prices as observed from 2010 to 2013 [124].

However, generating solar power can also have direct economic benefits in addition to the indirect economic advantage of reducing utility bills. For example, in Orlando, FL, some utility companies offer a credit to customers who generate solar energy ($0.05 per kWh of solar power generated), and if any such electricity can be transferred to the main power grid, utility companies typically buy this electricity for the same retail price.

3.1.3.2 Electric Vehicle role in reducing the reliance on grid electricity

As discussed earlier, EVs are included in this study as part of the energy supply system for the modeled NZEB. The EV is modeled as a battery that can be connected to the home during certain hours of the day and certain days of the week. This study assumes that the vehicle is used to go to work between 9:00AM to 5:00PM, and is then connected to the building for the rest of the day. For modeling purposes, some specifications with respect to the EV in this study should be defined before starting the analysis, including EV battery capacity, state of charge, hourly EV charge (EV battery charging rate per hour), and other specifications as applicable.

EV battery capacity is highly dependent on the characteristics of the vehicle, and can range from 19 kWh for a mid-sized sedan to 30 kWh for a full-sized SUV [125]. This study assumes that the lithium–ion batteries is used as described for a Nissan EV, the EV batteries of which are said to be able to store up to 24 kWh [126]. The hourly EV charge depends on the battery size, the charging level, and other important factors. Assuming an average vehicle range, it generally takes 4 to 8 hours for an EV battery to be fully charged [127], so the hourly EV charge in this study is assumed to range from 3 kW/hr to 6 kW/hr.

The electricity that can be transferred to the building from the EV battery and vice versa is highly dependent on the amount of electricity that is left in EV battery when it reaches home. In this analysis, the state-of-charge (SOC) variable is used to determine how much electricity is still in the EV battery when the EV returns home. The SOC when the vehicle returns home depends on the distance that the vehicle needs to travel to reach home, which in turn may vary depend on the specific characteristics of each region. This study therefore uses the average returning SOC value as a starting point, and different ranges are applied to the analysis afterward to see the effect of this parameter on the required electricity from the power grid. All of the EV-related data and assumptions used in this study are summarized in Table 4 below.

Table 4. Model Parameters

Parameter	Source	Values & Ranges
EV Battery Capacity (kWh)	[125]	19-30
Hourly EV Charge (kW/hr)	[127]	3-6
Solar Photovoltaic Production Incentive ($/kWh)	[128]	0.05
Electricity to Grid Price ($/kWh)	[129]	0.0757

3.1.4 Power Distribution System

The role of Building Energy Management Systems (BEMS) is becoming more significant as the importance of providing the necessary thermal comfort, visual comfort, and indoor air quality is receiving more attention, especially in situations where fossil fuel consumption, GHG emissions, and price fluctuations are major obstacles to meeting the need for an energy-efficient building [130]. While the concept of BEMS generally applies to controlling HVAC systems and determining the operation times in order to reduce energy consumption without compromising comfort [130], this study attempts to use this management tool to establish a connection between different energy sources within the building and determine the flow of electricity between the main battery, the EV battery, and the power grid. In a NZEB, different types of energy sources should be used in conjunction with each other and with the conventional power grid. This study assume that all of the power generated through the solar panels and the electricity from the EV battery are stored in a main battery already designed for this purpose. However, the specific technological advancements to be used in such a power distribution system are beyond the scope of this study.

This study attempts to develop an algorithm in which different energy sources interact with the grid in order to provide enough electricity to meet the energy demand of the building, while also transferring any surplus generated electricity to the grid and obtaining any additional required electricity from the grid during off-peak hours. In this algorithm (Figure 14), two possible situations are considered:

a) **The EV is connected to the building;**

In this case, the EV is considered as part of the energy supply system of the building. This study assumes that the vehicle is used to drive the owner to work every day at 9:00AM and then return home by 5:00PM; during this time, the vehicle is therefore disconnected from the building. When the EV is connected to the building and is not fully charged, the algorithm checks whether or not the amount of onsite renewable generated electricity is greater than the amount of energy consumption for that specific hour of the day, in which case the excess amount of generated electricity is used to charge the connected EV. This process continues until the EV battery is fully charged.

The next step is to see whether or not the main battery is fully charged. If not, then the onsite generated electricity is used to charge the main battery so that it can be used during on-peak hours, when the price of electricity is higher. After the EV battery and the main battery are both fully charged, if there is still any excess of generated electricity, it is transferred to the grid. In all of these steps, the algorithm checks if the generated renewable electricity is enough to supply the energy usage of the building.

If at any point the amount of onsite generated electricity is not enough to supply the energy demand of the building (especially during on-peak hours), then the system checks to see if there is any available electricity stored in the main battery. If there is, then the stored power in the main battery is used to power the building until it is fully depleted, after which the system checks if there is any electricity in the EV battery. Any stored power available in the EV battery is also used to power the building until the EV battery is also depleted, and if there is still insufficient power to meet the energy demand, then the remaining required electricity is taken from the grid.

b) The EV is disconnected from the building.

In this case, the main battery and the power grid are considered as the only available energy sources. Like in the previous scenario, the system checks to see whether or not the amount of electricity generated is greater than the energy consumption of the building. If not, then the system checks the main battery to see if there is enough electricity available in the main battery to power the building. If at any point the main battery is depleted, the power grid is used to provide the remaining electricity demand.

If at any time the onsite generated electricity is greater than the energy consumption of the building, the excess of generated electricity stores in the main battery for use during on-peak hours. Once the main battery is fully charged, any remaining surplus energy transfers to the grid.

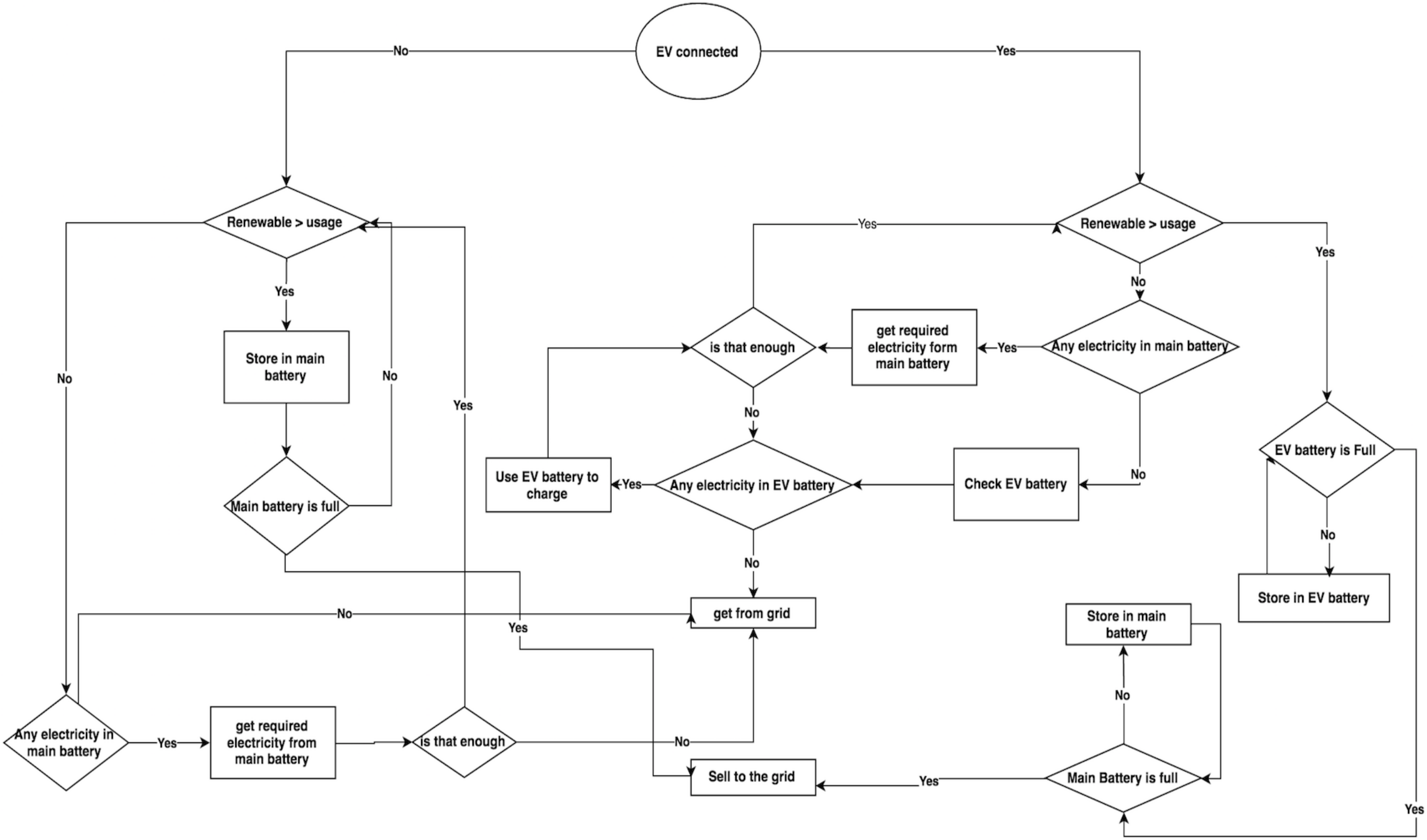

Figure 14. Power Distribution System Algorithm

3.1.5 Time-Based Electricity Pricing

Time-based electricity pricing is a pricing strategy in which power companies charge their customers extra for using electricity during certain time periods of the day ("on-peak hours") and offer credits to their customers who consume electricity during any other time period ("off-peak hours"). Utility companies have introduced this strategy to their customers to save money by reducing peak power demand [131]. For this purpose, a flat rate is applied to electricity consumption regardless of the time of usage, and then (depending on the usage hour and season) an extra charge is added to the total bill for using electricity during on-peak hours, while bonus credits are subtracted from the total bill for using electricity during off-peak hours [132]. Different electricity rates used in this study for different hours of the day are presented in Table 5 below for different seasons; in this study, these seasons have been separated into "summer" from April to October and "winter" from November to March.

Table 5. Hourly Electricity Pricing

	Summer (April-October)	Winter (November-March)
Flat rate ($/kWh)	0.0757	0.0757
On-peak charge ($/kWh)	0.06124	0.03316
Off-peak credit ($/kWh)	-0.01125	-0.01125

3.2 NZEB-ABM model development

In this section, the methodology used in this study is discussed in greater detail, and conceptual basis of this methodology is discussed in the following subsections. First, in Section 3.2.1, the modeling tools used are explained in more detail, and the characteristics of the building under investigation are discussed. Second, in Section 3.2.2, the process for achieving an energy-efficient building and the key parameters that most strongly affect the energy performance of the building are explained. Third, in Section 3.2.3, the process of adding solar panels to the building and how the model calculates the generated solar energy through solar panels are both described in more detail, based on the model illustrated in Figure 16. Fourth, in Section 3.2.4, the different agents used to construct the whole model in the simulated ABM environment are introduced. Fifth, in Section 3.2.5, the defined algorithm used to connect all of the different agents within the NZEB system is presented in Figure 19 and Figure 20. Also, a brief explanation of the logic of the algorithm is provided to better understand the different steps of the algorithm from start to finish.

3.2.1 Modeling a code-compliant building

In the first phase of this study, a two-story residential building is modeled in order to obtain the hourly energy consumption of a typical building by considering all of the different parameters affecting the energy usage, including the building envelope, the HVAC system, the lighting system, weather conditions, and so on. The software Designbuilder is used for this purpose; this software uses the Energyplus database introduced by the U.S. Department of Energy (DOE)[114]. Figure 15 below shows the layout of the designed house as modeled in the Designbuilder software.

Next, the weather database file is added in to perform an energy analysis. The basic properties of this building are summarized in Table 6.

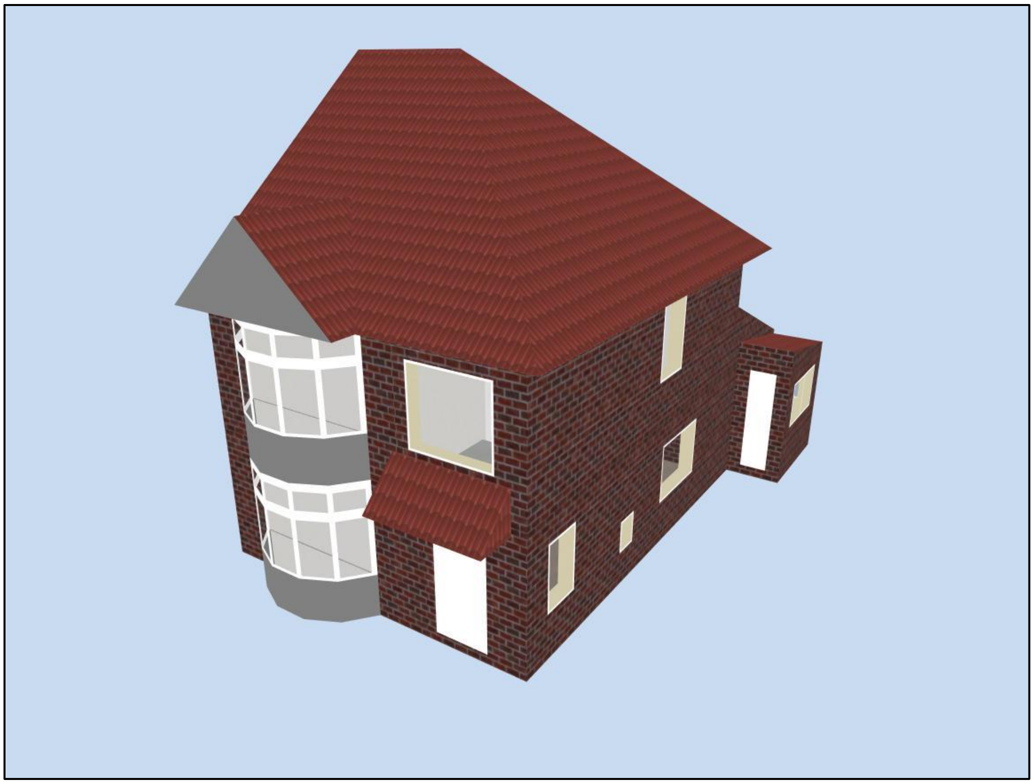

Figure 15. Developed model in Designbuilder

Table 6. Code compliant building properties.

Parameter	**Description/Value**
Location	Orlando, FL
Area	1831.46 (ft^2)
Net conditioned building area	1089.95 (ft^2)
Unconditioned building area	741.51 (ft^2)
HVAC system	Package DX
Chiller	DOE-2 Centrifugal/5.50COP
Lighting System	CFL
Cost	$ 269,642

Given the current systems and the assumption that grid electricity is needed to meet the entire energy demand of the building, the results of the energy analysis indicate that the energy use intensity (EUI) for this site is about 55.37 kBtu/ft^2. Compared to the national average, this building consumes about 25% less energy [133].

3.2.2 *Designing an energy-efficient building*

As discussed in the introduction, the first step in achieving a NZEB is to design an energy-efficient building. In this regard, it is required to investigate different design alternatives to find the best options that satisfy the requirements for different conflicting areas. The whole optimization process is explained in detail in the previous section (3.1.2). Since more than 66% of the energy consumption of residential buildings is related to their HVAC and lighting systems [2], this study focuses more on testing different HVAC and lighting systems to find the optimal system to reduce the building's energy consumption as much as possible. Based on the results of the optimization analysis, the items listed in Table 7 below have been changed, and the energy use intensity of the building is thereby reduced by 47% compared to the initial (“code-compliant”) design. Comparing the initial costs listed in Table 6 and Table 7, the initial cost is obviously increased by purchasing more energy-efficient HVAC and lighting systems.

Table 7. Energy efficient building properties.

Parameter	**Description/Value**
HVAC system	GSHP, Heated Floor, Nat Vent
Lighting System	LED with linear control
Cost	$ 306,752

3.2.3 Adding solar panels to the system

By definition, a net-zero-energy building should be an energy-efficient building first and foremost, and then the minimized energy consumption should be supplied through renewable energy sources such as solar panels. For this purpose, solar panels are added to the building in this step. In this regard, 1,722 square feet of photovoltaic solar panel area is placed at the roof of the building, and the energy analysis is performed again with the solar panels taken into account, and the results (including the hourly solar power generated through solar panels) are exported to perform more analyses and add other sources of electricity to the building. As can be seen in Figure 16 below, with the help of a pre-selected weather database, it is possible to track the position of the sun with respect to the building and the angle at which that sunshine ray hits the solar panels on the roof of the building. These values are different for different times of the year.

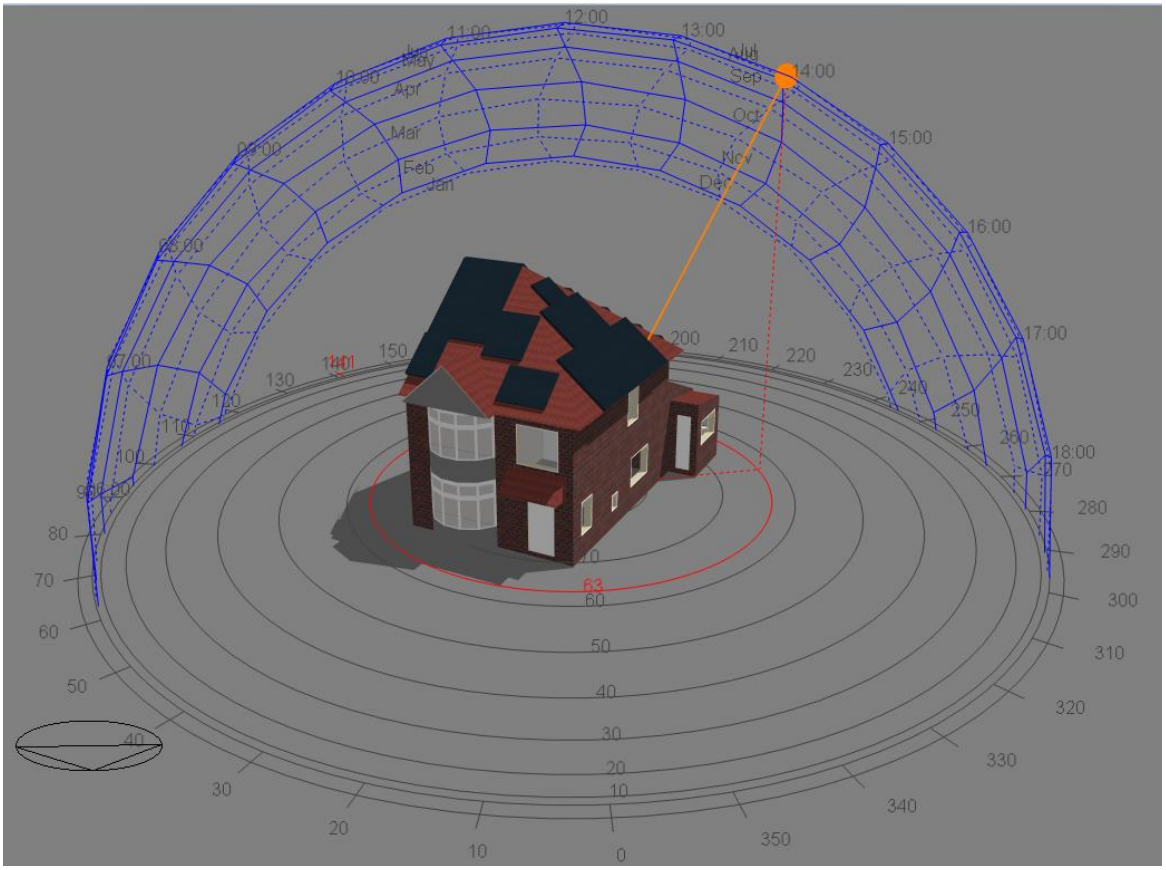

Figure 16. Developed model in Designbuilder and sun locations with respect to the building at different times of the year (e.g., 15th of July, 2:00 PM)

Now that an energy-efficient building has been properly designed and renewable energy sources have been added to the system as needed, the next step is to model all of these parameters along with other components of the system, such as the EV battery. In the next section, the methodology used to model the whole system is described in detail.

3.2.4 Agent-based modeling

In this study, four different agents (building, EV, solar power and grid electricity) are considered for the purpose of achieving a NZEB: the building itself, the EV, the solar panel system, and the power grid. The main battery installed in the building, the EV battery, and the solar power system all interact with each other and with the power grid. The primary purpose of this study is to investigate the possibility of reducing the building's reliance on the power grid by storing solar power during sunny hours of the day and then consuming the stored energy during on-peak hours when the price of electricity is higher. In this regard, the EV battery is also considered as a battery that can store electricity during off-peak hours and then help to supply power to the building during on-peak hours. ABM can track the behavior of different heterogeneous agents on a micro-level basis although it is also possible to take into account the effects of macro-level policy implications [91].

3.2.4.1 Building Agent

In this ABM model, the building agent carries information regarding the hourly electricity usage of the building and the available charge of the main battery installed in the building while the main battery is responsible for storing electricity from other energy sources, including solar power and electricity from the EV battery. The main battery is also in communication with the power grid to transfer electricity to or from the grid network. Tesla power wall battery specifications are used in this study for the main battery. Each battery has panels that can store 10 kWh to 100 kWh of electricity [134]. These batteries are designed to provide power for sustainable homes. A schematic view of this battery can be seen in Figure 17. During the analysis, the amount of main battery capacity changes to simulate and analyze the effect of the main battery capacity on the amount of electricity required from the grid.

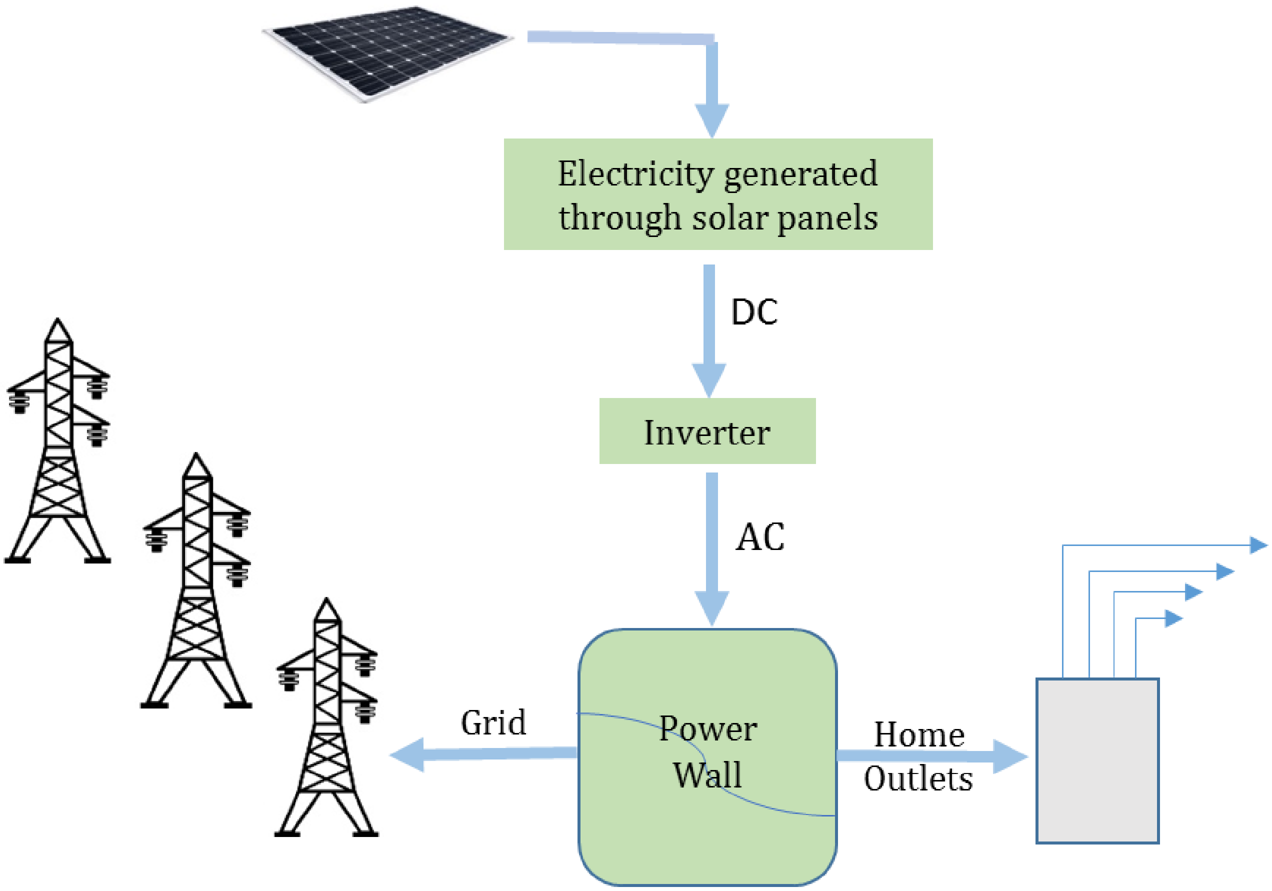

Figure 17. Schematic view of mounted power wall

3.2.4.2 Electric Vehicle Agent

The EV battery agent plays an important role in achieving a NZEB, as it is considered to be a remote power storage unit that can store electricity during off-peak hours and supply electricity to the building during on-peak hours. The EV battery can also be a valuable source of electricity during emergency situations such as power outages, and the EV battery itself can be recharged from the stored electricity in main battery or from the power grid. A schematic view of the car agent modeling is presented in Figure 18. It is assumed that the vehicle leaves home at 8 AM and returns home by 5 PM every day. The EV battery storage is estimated to range between

19 kWh and 30 kWh [135], so a slider will be modeled to change the EV battery capacity and then track the required electricity from the grid to better understand the effect of EV battery capacity on the required electricity from the grid.

Figure 18. Schematic view of vehicle agent modeling

3.2.4.3 Grid Agent

In 2015, 67% of the electricity generated in the U.S. (4 trillion kWh) was produced from fossil fuels such as coal, natural gas, and petroleum [136]. On the other hand, 1,415 billion kWh of this electricity (approximately 35%) was consumed by the residential sector [137]. Based on this information, reducing the required electricity from the grid for residential buildings by substituting other energy sources to supply their power demand can help to greatly reduce fossil fuel usage in the U.S. As mentioned earlier, the whole energy supply system of the building as modeled in this study interacts with the grid. The purpose of every single part of this system is to reduce the building's overall reliance on grid electricity by integrating other sources of electricity into the building, such as solar power and an EV battery. For this purpose, three mechanisms have been considered simultaneously. The first of these mechanisms seeks to reduce the required electricity from the grid by generating solar power and storing it in the main power wall battery. The second mechanism uses the stored electricity in the EV battery, transferring it to the building as needed. Finally, the third mechanism draws electricity from the grid during off-peak hours and provides any excess electricity to the grid during on-peak hours. In this regard, two separate variables are defined to track the amount of electricity drawn from the grid and the amount of electricity contributed back to the grid. These three mechanisms work under a predefined algorithm space, which can determine parameters such as the flow of electricity from or to the power grid as well as the main source of electricity supply for the building at each hour of the day by considering important parameters such as the main battery capacity, the EV battery capacity, the state of charge for each battery, the available charge in the EV battery, and so on. This algorithm is explained in detail in the next section.

3.2.5 Governing algorithm

As mentioned earlier, the defined algorithm is a key element that defines the logic of the model in this study. A visual description of this algorithm is presented in Figure 19 and Figure 20, each representing one of the two scenarios described below. These algorithms are defined in the Anylogic environment and, as shown in Figure 19 and Figure 20, start by evaluating whether or not the EV is connected to the building. As discussed earlier, this study assumes that the vehicle leaves home every day at 8 AM for work and returns home by 5 PM, so based on the hour of the day, the algorithm determines if the vehicle is connected or not. One of two possible scenarios is then simulated, depending on whether or not the vehicle is connected.

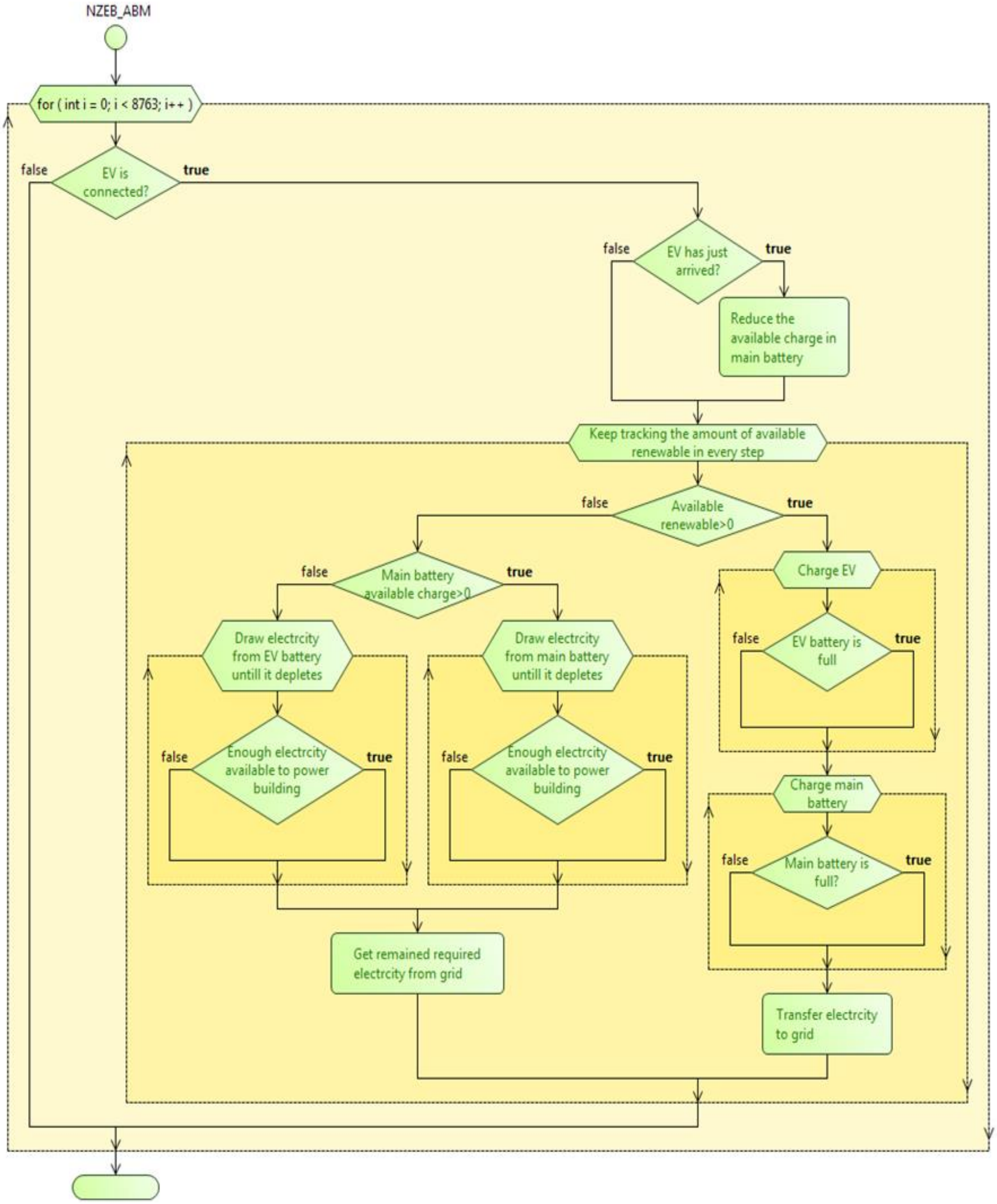

Figure 19. Governing algorithm of the system (a)

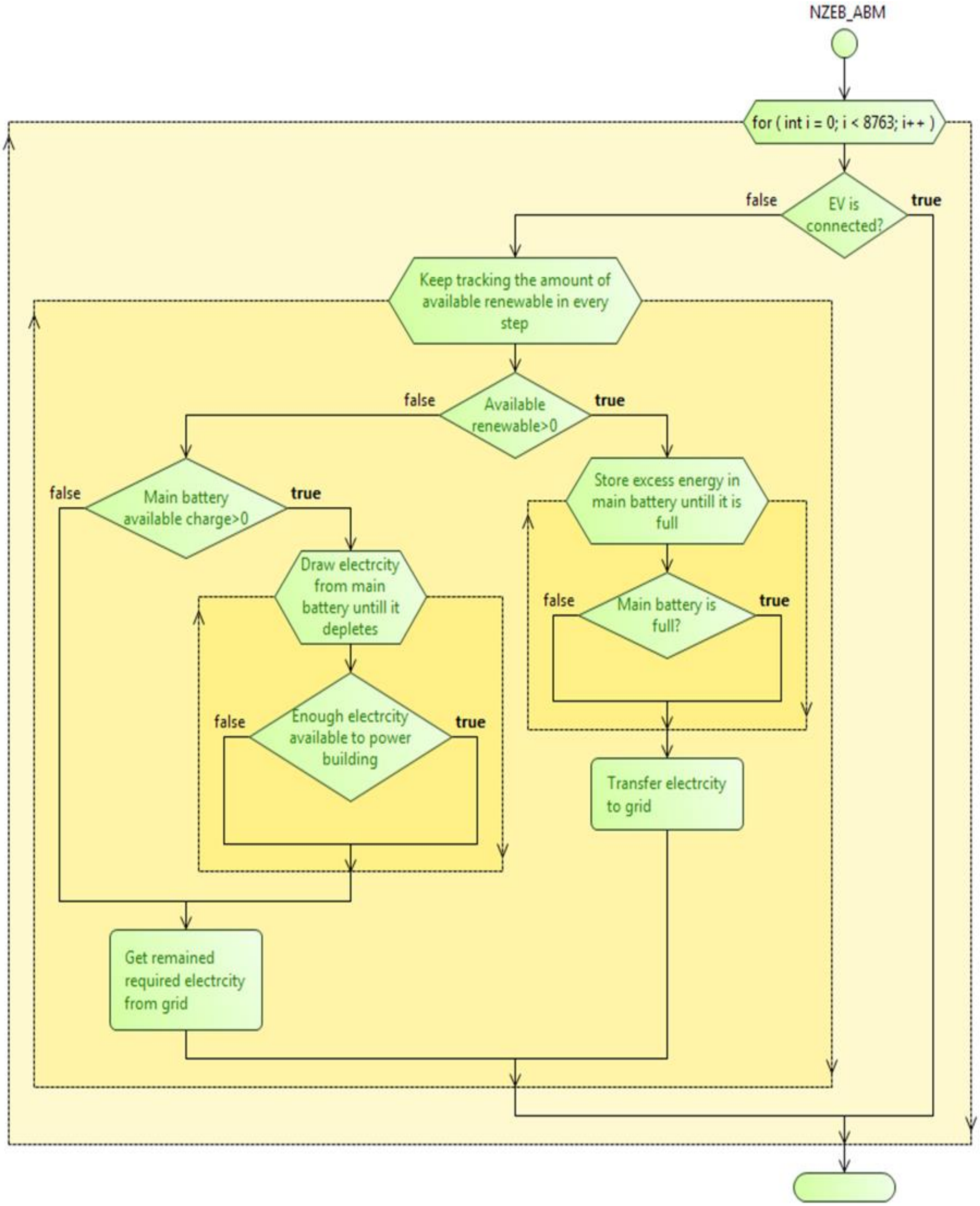

Figure 20. Governing algorithm of the system (b)

CHAPTER FOUR: ANALYSIS AND RESULTS

In this chapter, first the results of the first case study (NZEB-VBA) are discussed. In this regard, results of the energy analysis, comparison of the purchased electricity from grid for two NZEB and conventional cases, monthly transferred electricity to the grid, and electricity cost comparison for two different cases are presented. At the end, the results of the sensitivity analysis are discussed in detail. In the second part of this chapter, the results of the second study (NZEB-ABM) are presented. Amount of purchased electricity from grid and transferred electricity to the grid for two cases of NZEB and conventional cases, environmental impacts of implementing discussed methodology, electricity cost comparison for two cases, and amount of transferred electricity from home to vehicle are among the covered topics in this section. At the end, the validation and verification process of the developed model is discussed in further detail.

4.1 Case Study for NZEB-VBA Model

The results of the analysis are presented in the following sections. First, the results of the energy analysis are presented in Section 4.1.1. Next, electricity consumption rates are compared and discussed in Section 4.1.2 for two scenarios, the first scenario being where the only available source of energy is grid electricity (the “conventional” scenario) and the second scenario being where renewable energy sources and the use of an EV battery are introduced as part of the energy portfolio (the “NZEB” scenario). Afterward, the amount of electricity transferred to the grid during different months of the year is presented in Section 4.1.3, followed by a price comparison for the two above-mentioned scenarios in Section 4.1.4. Finally, the results of a sensitivity analysis are presented in Section 4.1.5 to analyze the effects of input variables (main battery capacity and state of charge) on the annual electricity consumption of the building modeled in this study.

4.1.1 Energy Analysis Results

The results of the energy analysis are illustrated in Figure 1 to 7 and summarized in Table 8, including the monthly energy consumption of each type of power usage within the building (lighting, heating, cooling, etc.), as well as different sources of energy and/or energy savings, such as heat gain through windows and power generated through solar panels. Different parameters affecting the energy consumption of the building (outside temperature, humidity, building envelope, occupancy, heat gain through interior and exterior windows, etc.) have also been considered in this analysis, while Table 9 also summarizes the temperature and dry-bulb temperature for each month of the year. In Table 8, zone-sensible cooling and heating are defined as the sensible cooling and heating effect of any air introduced into the conditioned zone through the HVAC system [138]; for example, the heating effect of fans can be considered as a zone-sensible cooling load. Looking at Table 8, the results make sense in that, as the temperature increases from January to September (Table 9), the cooling load increases and reaches its maximum value in July, after which the temperature begins to decrease as the weather gets colder; although the month of February does not seem to follow this trend, this could be due to unusual weather conditions. The same trend can be seen in reverse for the heating load; as the number of cold days per month increases relative to the corresponding number of hot days, the heating load increases. The amount of electricity generated via the installed solar panels also can be tracked on a monthly basis (Table 8). This analysis shows that, as the number of sunny hours per day and/or the number of sunny days per month increase, the solar panels receive more sunlight and can therefore generate more and more electricity. This amount, as seen in Table 8, has an increasing trend until the end of July, after which it gradually starts to decrease until a sharp reduction us observed at the beginning of October. These differences in energy consumption trends are easily justifiable based on intuitive deductions from the surrounding environment. On the other hand, other contributors to the energy consumption of the building (room electricity, lighting and equipment components, etc.) have a nearly constant energy consumption rate with minimal variations during different months of the year, regardless of temperature changes or weather conditions.

Table 8. Energy Analysis Results

Energy analysis results (kWh)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Room Electricity	196.6	178.0	197.6	190.4	196.6	191.4	196.6	197.1	190.9	196.6	190.9	197.1
Lighting	133.4	117.1	123.2	117.4	115.3	106.9	113.6	117.4	117.5	129.5	125.1	132.2
Heating (Electricity)	28.7	24.5	34.7	1.4	0.0	0.0	0.0	0.0	0.0	1.8	5.2	25.9
Cooling (Electricity)	22.5	13.1	26.3	134.9	303.6	433.1	661.3	510.0	386.2	245.8	36.4	17.3
DHW (Electricity)	89.0	80.4	89.0	86.2	89.0	86.2	89.0	89.0	86.2	89.0	86.2	89.0
Generation (Electricity)	1,280	1,010	1,797	2,302	2,509	2,119	2,336	2,298	2,221	1,441	1,446	1,305
Computer + Equipment	196.6	178.0	197.6	190.4	196.6	191.4	196.6	197.1	190.9	196.6	190.9	197.1
Solar Gains Exterior Windows	811	564	831	1,003	1,046	920	977	972	990	731	868	864
Zone Sensible Heating	57.4	49.0	69.4	2.7	0.0	0.0	0.0	0.0	0.0	3.5	10.4	51.8
Zone Sensible Cooling	51.5	29.5	59.5	312.9	675.1	941.3	1,392	1071	827.8	519.3	81.1	39.4

Table 9. Temperature Data for Different Months of the Year

Temperature	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Air temperature (C)	19	21	22	24	25	25	25	25	25	24	23	21
Outside dry-bulb temperature (C)	14	17	18	21	24	26	26	26	26	23	20	16.3

Figure 21 is presented below to better understand the results of the energy analysis of the building in question. In this graph, the energy consumption and generation for different months of the year can be observed for a quick visual comparison. The most significant variations occur for cooling load and electricity generation through solar panels during different months of the year, because unlike many areas in the U.S., heating load does not contribute significantly to the energy consumption of the building. As seen in this graph, as the hotter days of the year approach, the cooling load begins to increase significantly, while the opposite trend can be seen in the heating load. Except for the colder days in December, January and February, the heating load then becomes insignificant for the rest of the year. All other components (room electricity, lighting, hot water, etc.) have a relatively steady rate of variation for different months of the year. The negative values in the graph indicate the electricity generated via solar panels, which decreases the overall daily energy consumption.

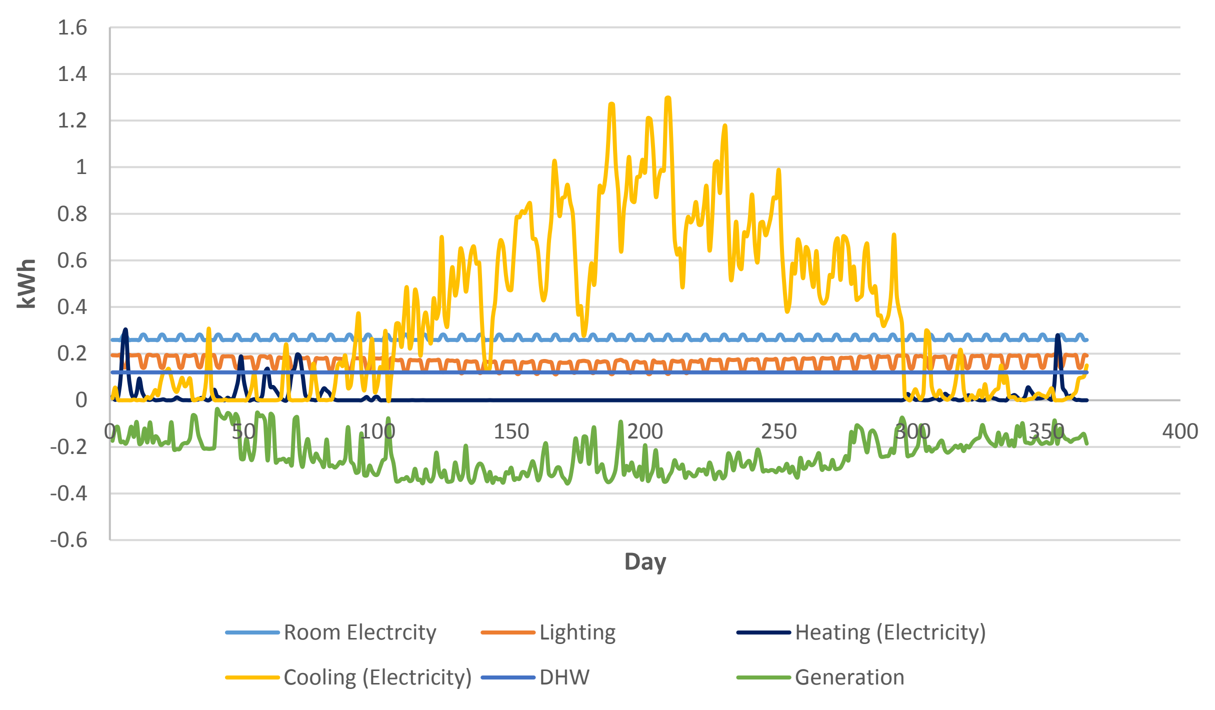

Figure 21. Average Daily Energy Consumption and Generation of the Building

4.1.2 Electricity Consumption

The hourly and cumulative rates of purchased electricity from the grid for the studied building are presented in Figure 22 and Figure 23, respectively, each comparing the purchased electricity of the building with and without the integration of solar panels and the EV battery (“NZEB” and “conventional”, respectively).

The purchased electricity drops significantly in the NZEB scenario compared to the conventional scenario, with the average hourly decrease in grid reliance being roughly 61% year-round, while the most visible hourly decrease (93%) was in September. The gap in purchased electricity between the two scenarios is greatest during the summer due to increased solar power generation from longer sunny periods compared to other months of the year. From Figure 23, the overall year-round energy savings with the NZEB scenario is 66%.

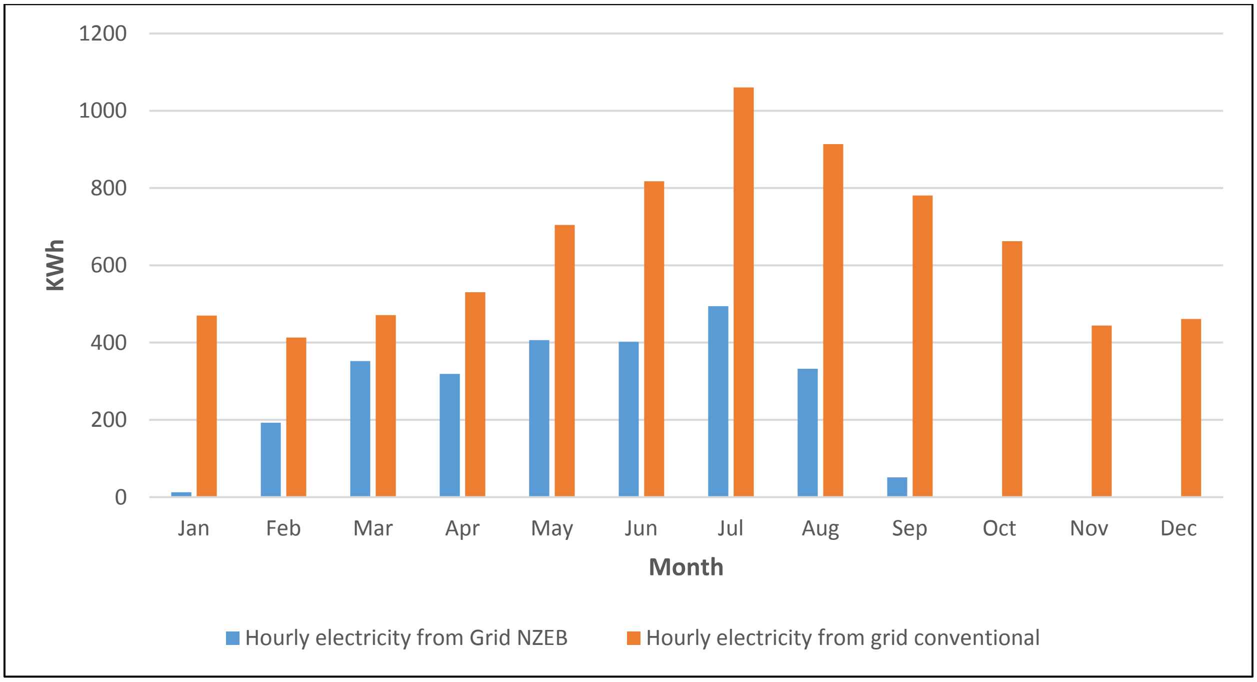

Figure 22. Comparison of Hourly Energy Consumption of the Building for Conventional and NZEB Scenarios

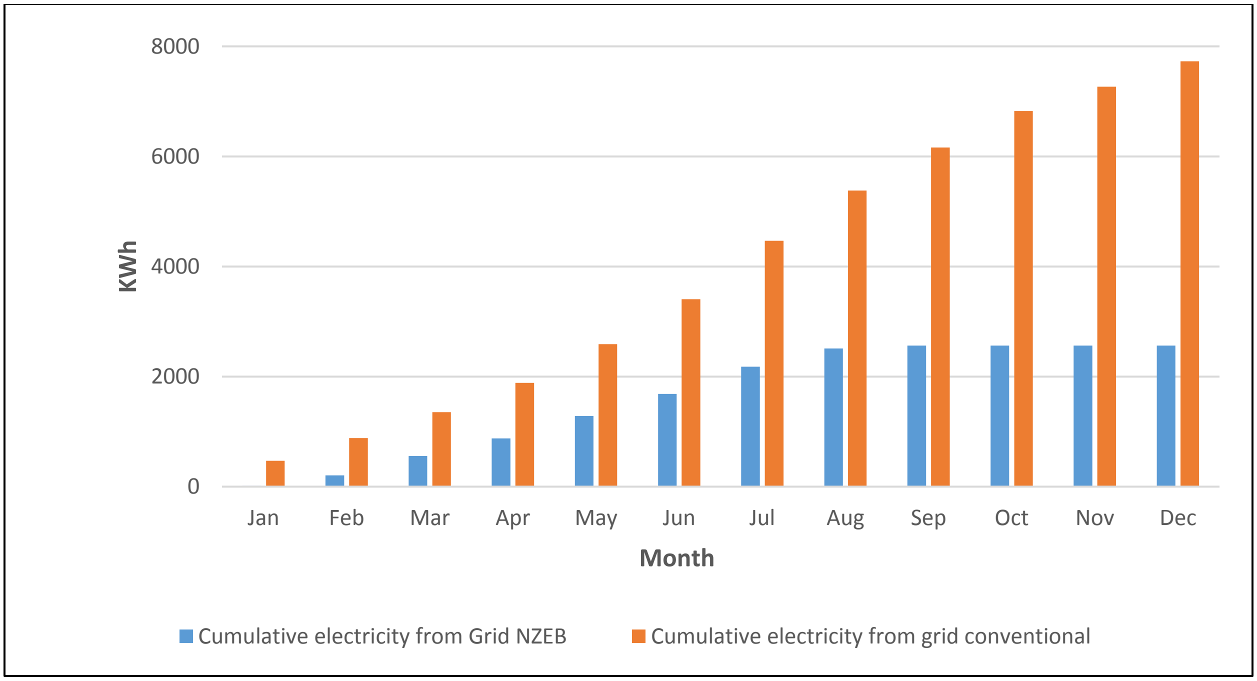

Figure 23. Comparison of Cumulative Energy Consumption of the Building for Conventional and NZEB Scenarios

4.1.3 Electricity to Grid

As mentioned earlier, and as noted in the algorithm discussed in Section 3.1.4, any remaining excess amount of onsite generated electricity from the solar panels and from the stored electricity provided through the EV battery can be transferred to the power grid. Figure 24 presents the amount of electricity that can be transferred to the grid in different months of the year. The amount of electricity transferred to the grid in each month is highly dependent on the electricity consumption of the building, as well as the monthly electricity generation rate from the solar panels, so finding a constant trend in this case is not possible on a yearly basis. However, jumps in the amount of electricity transferred to the grid from month to month can be better understood by looking at the electricity consumption of the building (Figure 22) and the amount of solar energy generated (Table 8). In general, less electricity is transferred to the grid when the monthly energy consumption is higher and/or when the amount of generated solar energy is lower, in which case the main priority of the system is to supply the energy demand of the building first and then transfer any excess amount of generated energy to the grid. For example, the amount of electricity to grid is higher in September than October, November, or December, but looking at Figure 22 and comparing electricity consumption rate in September with those in each of the last three months of the year, this may sound confusing. This confusion may be clarified by following the trend of electricity generation (Table 8) and analyzing the solar energy generation in each of the latter months.

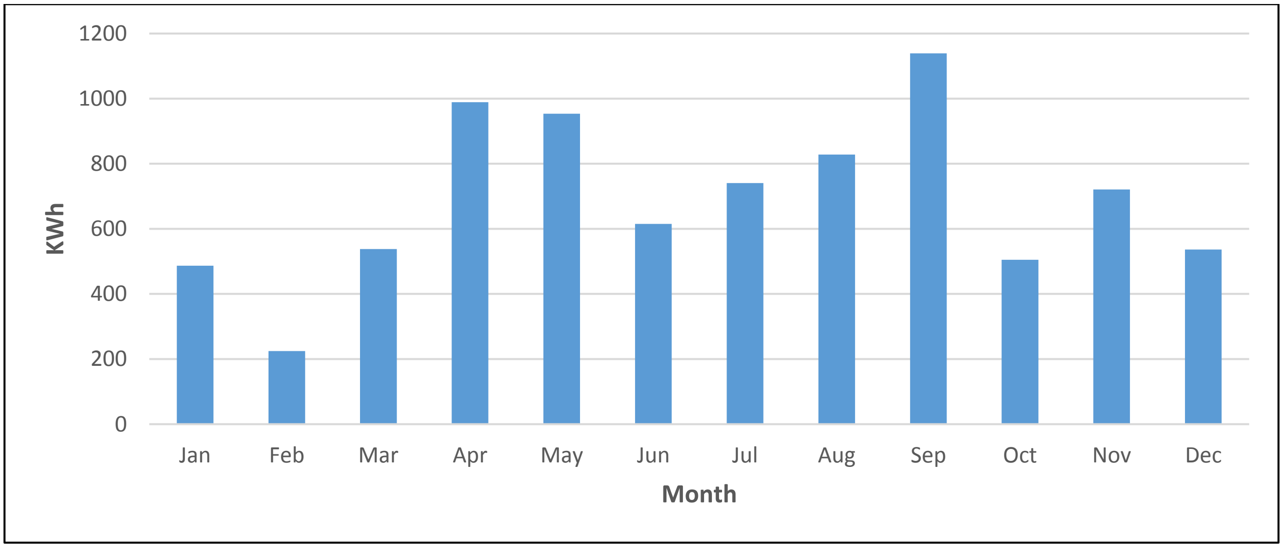

Figure 24. Monthly Amount of Electricity Transferred to the Grid

4.1.4 Price Comparison

A very important incentive for a NZEB is the potential economic advantages of such a building, as a true NZEB would effectively reduce its utility bills to zero. In the process, it is also possible to earn money to compensate for the installation costs of solar panels and other technologies required for the NZEB. Calculations regarding the monetary value of energy in this study are divided into two parts. The first part investigates how much in savings may be possible by reducing the energy consumption of the building, assuming that no credit is given to the customer for selling electricity to the grid or for producing renewable energy from solar panels or other energy sources. In the second part, however, a production credit is provided to customers who generate solar energy and then sell the excess amount of onsite generated electricity to utility companies such as the Orlando Utility Commission (OUC) [128].

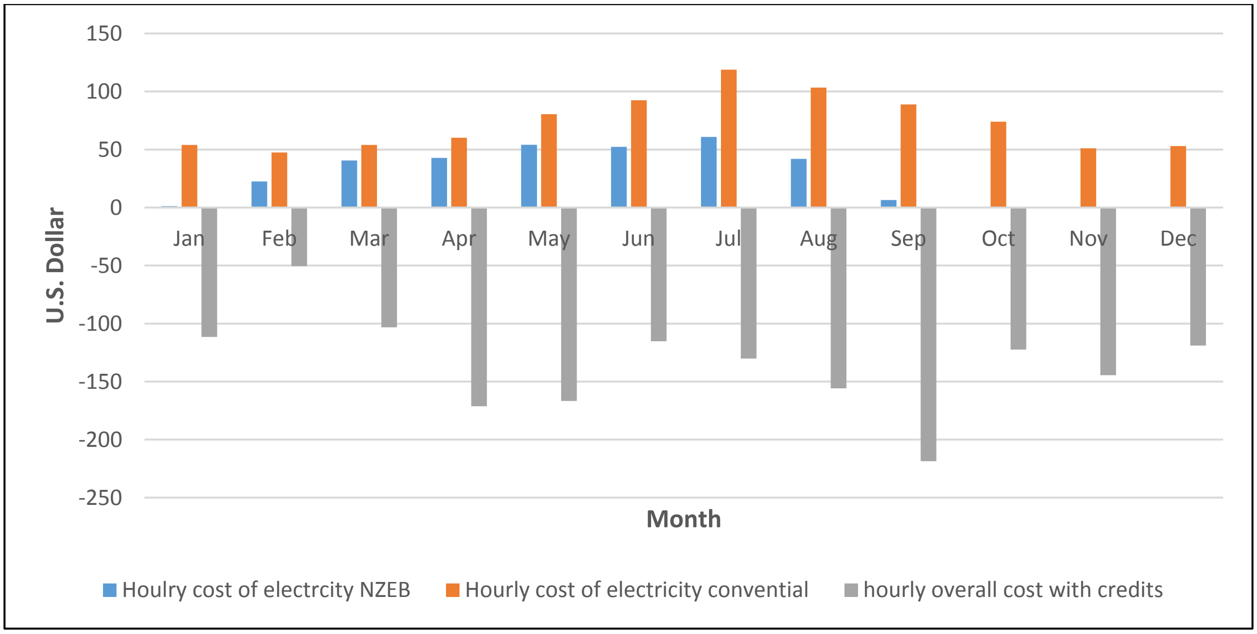

Figure 25. Monthly Electricity Bill Price Comparison

The differences in conventional and NZEB electricity costs (with and without credits) are presented in Figure 25, where it becomes immediately clear how much can be saved in electricity costs with an NZEB. Many utility companies provide incentives for their customers to encourage the integration of renewable energy sources into their energy portfolios. Considering all of these credits together, the final electricity price for the NZEB in this study with all of the above-mentioned considerations and energy sources taken into account is shown in Figure 25. This graph shows that, when the aforementioned credits are taken into consideration, the net electricity price is negative throughout the year, meaning that customers can effectively pay nothing for electricity and can even earn money as a result.

4.1.5 Sensitivity analysis

As previously discussed, each of the aforementioned parameters in this analysis, (EV battery capacity, main battery capacity, hourly EV charge, SOC, etc.) have different ranges that must be considered in any practical analysis. The previous analyses described above used average values for each of the specified parameters. However, this section demonstrates the effect of these parameters (more specifically, the main battery capacity and the SOC) on the required electricity from the power grid and on the transferred electricity to the grid, and then compares the results as appropriate. For this purpose, two maximum and minimum ranges and three median values for main battery capacity (10 kWh to 90 kWh) and SOC (0.1 to 0.9) are tested, and the results are presented in Figure 26 and Figure 27. The values of the aforementioned parameters and the corresponding results are presented in Table 10 and Table 11 for comparison.

Table 10. Required Electricity from the Grid for Different Values of SOC

State of Charge	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.1	95.8	487.4	767.2	693.8	841.3	776.8	851.1	619.8	106.6	160.5	13.9	41.8
0.3	32.5	392.4	622.2	568.8	696.3	651.8	725.9	512.1	81.2	127.6	0.0	6.3
0.5	17.7	325.7	497.2	443.8	551.3	526.8	609.4	422.1	66.2	37.6	0.0	0.0
0.7	12.7	192.7	352.2	318.8	406.3	401.8	494.4	332.1	51.2	2.1	0.0	0.0
0.9	7.7	90.3	203.6	194.8	262.0	278.5	380.0	242.1	36.2	0.0	0.0	0.0

Table 11. Amount of Electricity Transferred to the Grid for Different Values of Main Battery Capacity

Main battery capacity (kW)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10	786.2	574.4	1,303	1,799	1,858	1,415	1,542	1,582	1,620	906.8	962.1	813.1
30	353.4	278.7	771.9	1,233	1,248	845.3	943.2	970.2	1,071	426.7	573.9	387.6
50	331.7	118.7	306.7	733.6	670.2	378.2	507.1	600.2	981.0	366.5	573.9	381.3
70	311.7	66.6	25.0	281.5	165.6	37.5	175.3	338.6	908.0	354.4	573.9	381.3
90	291.7	46.6	5.0	86.5	26.2	3.5	78.1	217.2	866.2	354.4	573.9	381.3

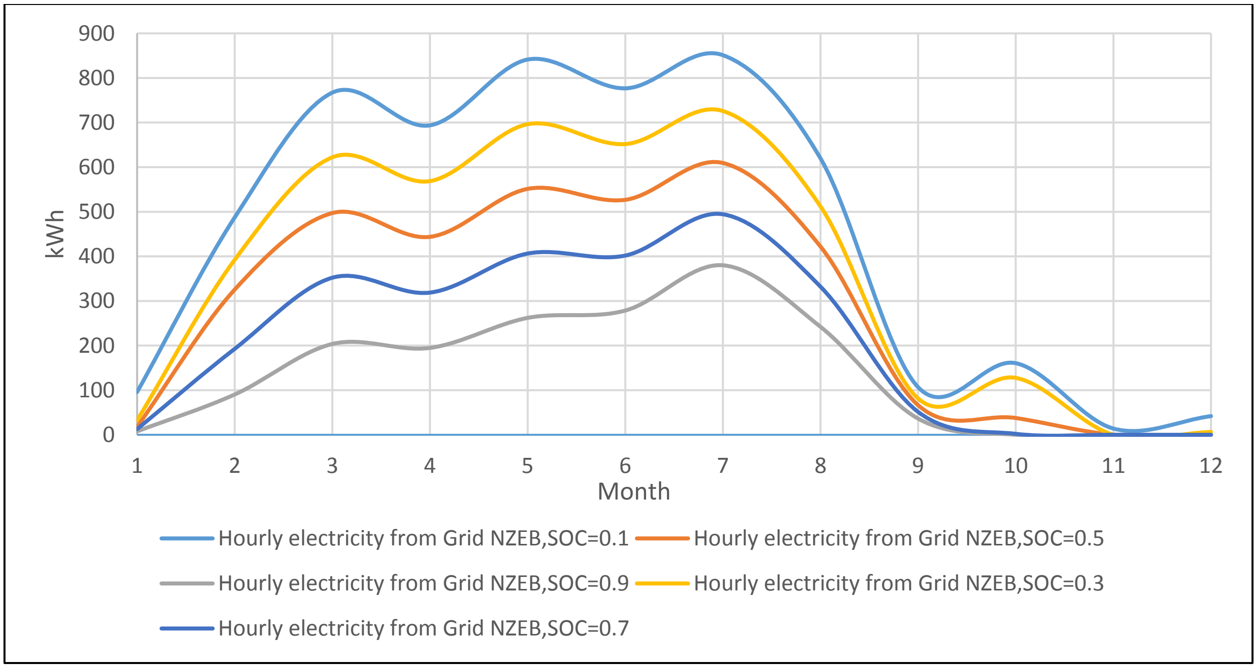

Figure 26. Electricity from the Grid for Different Ranges of SOC

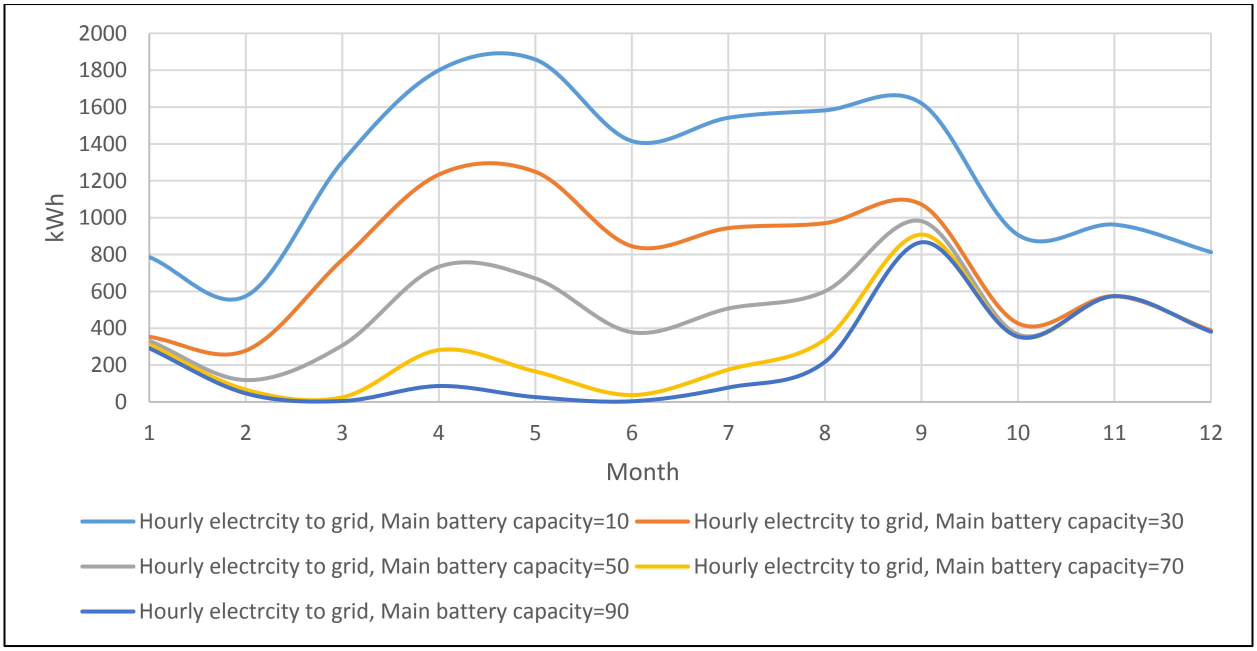

Figure 27. Electricity Transferred to the Grid with different ranges of main battery capacity.

The graph above (Figure 27) shows that the lowest grid electricity demand is evident whenever the SOC is at its highest value. For instance, in January, the required electricity from grid is reduced by 92% as the SOC increases from 0.1 to 0.9, which shows how significant the effect of state of charge is on demand from the power grid. On a year-round basis, an average reduction of 80% in the required electricity from the grid is observed for the two maximum and minimum assigned values of SOC. This is because, based on the defined algorithm, after supplying the energy demand of the building and before storing any electricity in the main battery, the system stores the surplus onsite generated electricity in the EV battery. Having more electricity available in the EV battery when the vehicle returns home for the day means that less electricity can be stored in the EV battery afterward, meaning that more energy is available to be stored in the main battery and/or used to supply the energy demand of the building. The same rule also applies for the EV battery capacity; as the EV battery capacity increases, more electricity can be stored in the EV battery, and so more electricity is required from the grid to fully charge the EV battery. In other words, decreasing EV battery capacity has the same effect as increasing the state of charge.

The results from Figure 27 match the stated expectations as well, in that more capacity to store the surplus onsite generated electricity can justify less transferred electricity to the grid. As seen in Figure 27, the highest amount of electricity supplied to the grid is observed when the capacity of the main battery is at its lowest value; hence, as the capacity of the main battery increases, the amount of electricity supplied to the grid decreases. For instance, as seen in Table 11 for the month of May, the observed reduction in electricity transferred to the grid is over 98%. On average, a 77% reduction in the amount of electricity transferred to the grid is observed for different months of the year as the main battery capacity increases from 10 kWh to 90 kWh. This is understandable because, based on the algorithm used, fully recharging the main battery is given priority over transferring electricity to the grid.

4.2 Case Study for NZEB-ABM Model

This section presents a comparison between the hourly and cumulative electricity consumption, the hourly and cumulative electricity price, the fossil fuel consumption rate for generating electricity, and CO_2 emissions for two cases with respect to conventional and NZEB methods. In this regard, “conventional” refers to the case where the entire electricity demand of the building is supplied through grid electricity, while “NZEB refers to the case where different sources of electricity (EV batteries, solar panels, and grid electricity) work together under the governing algorithm to supply the required electricity of the building.

4.2.1 Energy analysis results

In this section, the results of the energy analysis are discussed. As mentioned earlier, energy analysis is performed considering weather situation and building occupancy condition. Different loading conditions can vary significantly based on the occupancy of the building. Figure 28 shows the monthly heating and cooling load as well as air temperature for different months of the year. As can be seen in this Figure, except few days from January through March and few days in November and December, heating load doesn’t exist in other months. On the other side, cooling load increases significantly during hot summer days and reaches to its peak in July and August. As the weather gets cooler by the end of October, cooling load decreases significantly. These data can be confirmed by looking at temperature changes throughout the year. As the temperature decreases in January and March, heating load increase and by increasing the temperature from

April, cooling load starts its increasing trend. Considering the weather situation in Orlando, Fl, the results are reasonable and match with real experience.

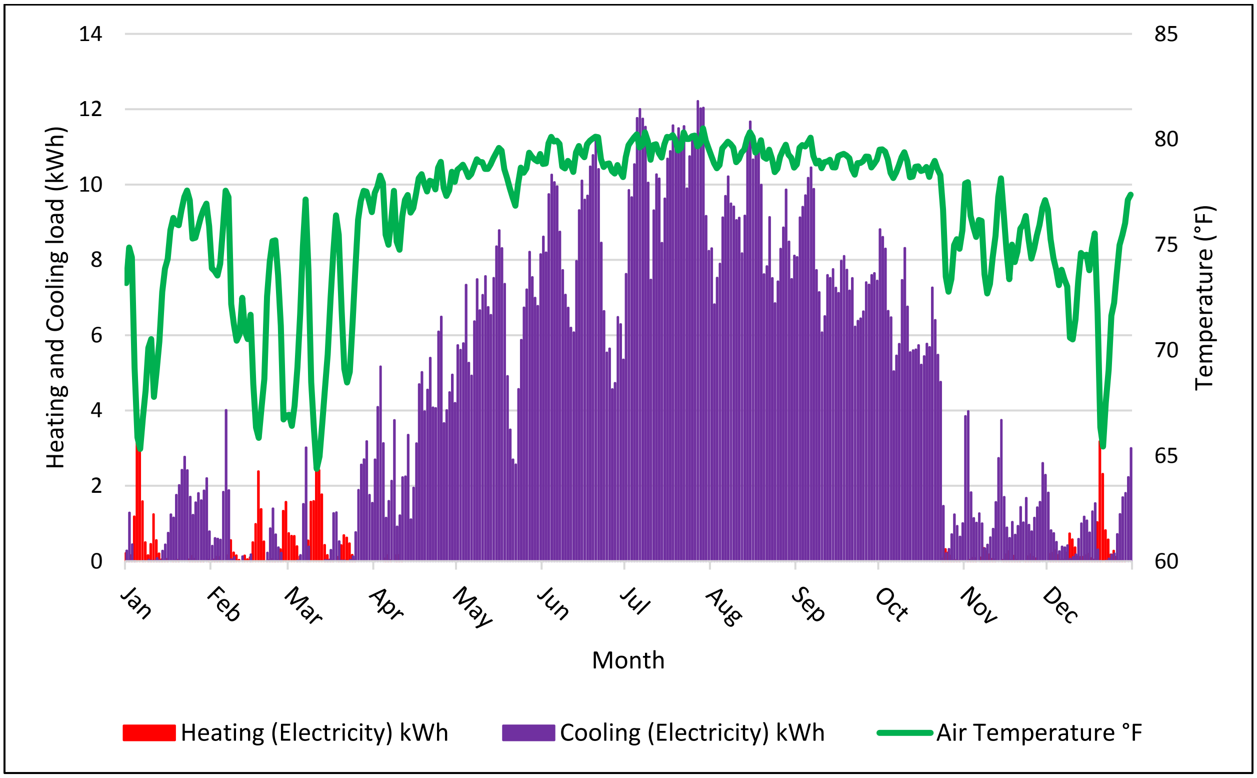

Figure 28. Heating and cooling load vs Air temperature

Figure 29 shows different electricity load shares in the building. It also shows the amount of monthly generated electricity through solar panels compared to electricity consumption in the building. As discussed earlier, heating load is negligible in most of the days of the year while cooling load is the dominant load during hot months of the year. As can be seen, as we get closer to hot summer months, the share of cooling load increases significantly and as the summer months finish, the cooling load share is decreased, even compared to other sectors. The generated electricity through solar panels is illustrated as a negative value because, unlike other loads, solar panels generate electricity rather than consume it. The trend of generated electricity by solar panels is reasonable as it is expected to see more electricity generation during the days in which more sunny hours are available.

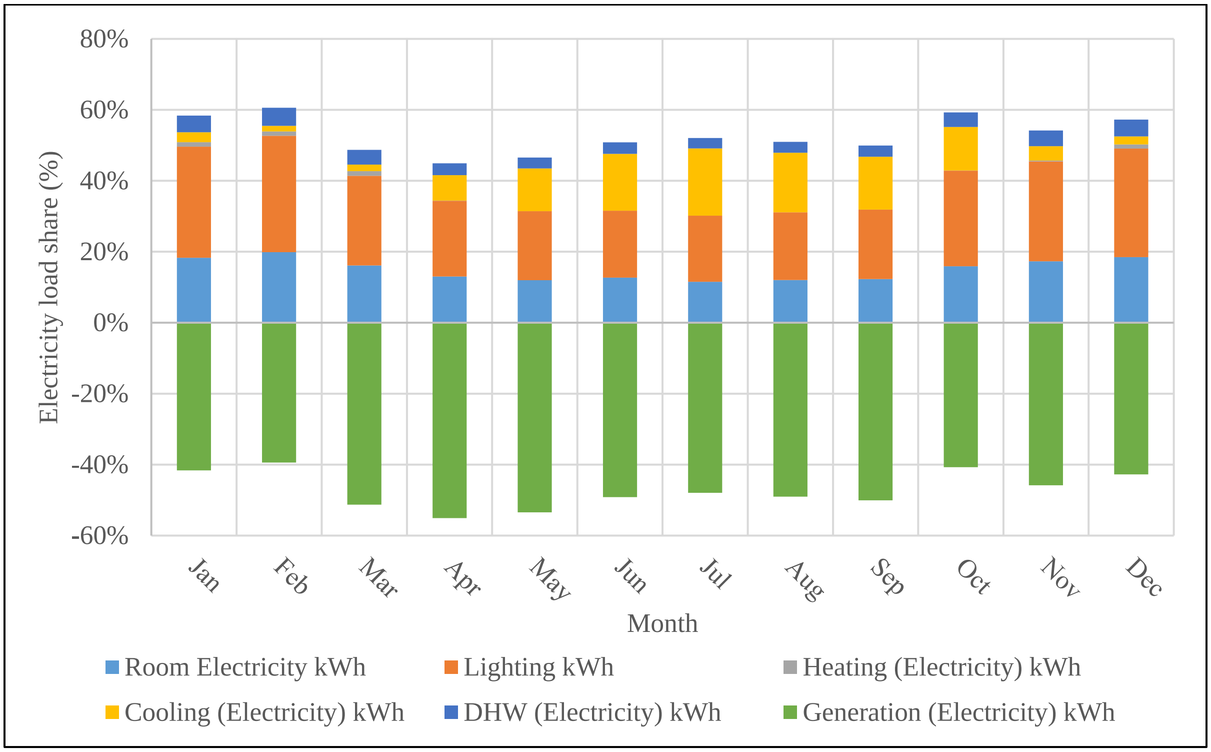

Figure 29. Heating and cooling load vs Air temperature

4.2.2 Electricity from/to grid

As stated in the introduction, the main purpose of this study is to investigate different ways to reduce the amount of required electricity from grid and thereby reduce the fossil fuel consumption needed to generate electricity. As seen in Figure 31, the analysis results show that, with the help of a properly designed NZEB system, the amount of electricity taken from the grid is reduced by 76% compared to a standard code-compliant energy-efficient building. This difference becomes more significant if the electricity consumption of an ordinary code compliant building is compared with a NZEB building, in which case there is a 90.2% difference in electricity consumption. Also, from the daily electricity consumption chart, it can be seen that, except for a few days of the year for which green dots are above blue ones in Figure 30, green dots are lower than blue ones, meaning that the amount of electricity required from the grid is much higher for conventional methods compared that required for a NZEB.

As can be seen in figure below, the green line falls as the summer ends. The reason is that during the summer, the energy consumption of the building is at its peak, and as a result more electricity is required from the grid and at the same time less electricity can be transferred to the grid, thus reducing the saving through selling electricity to grid. As the summer ends, more electricity can be transferred to the grid and saving through selling electricity to grid increases.

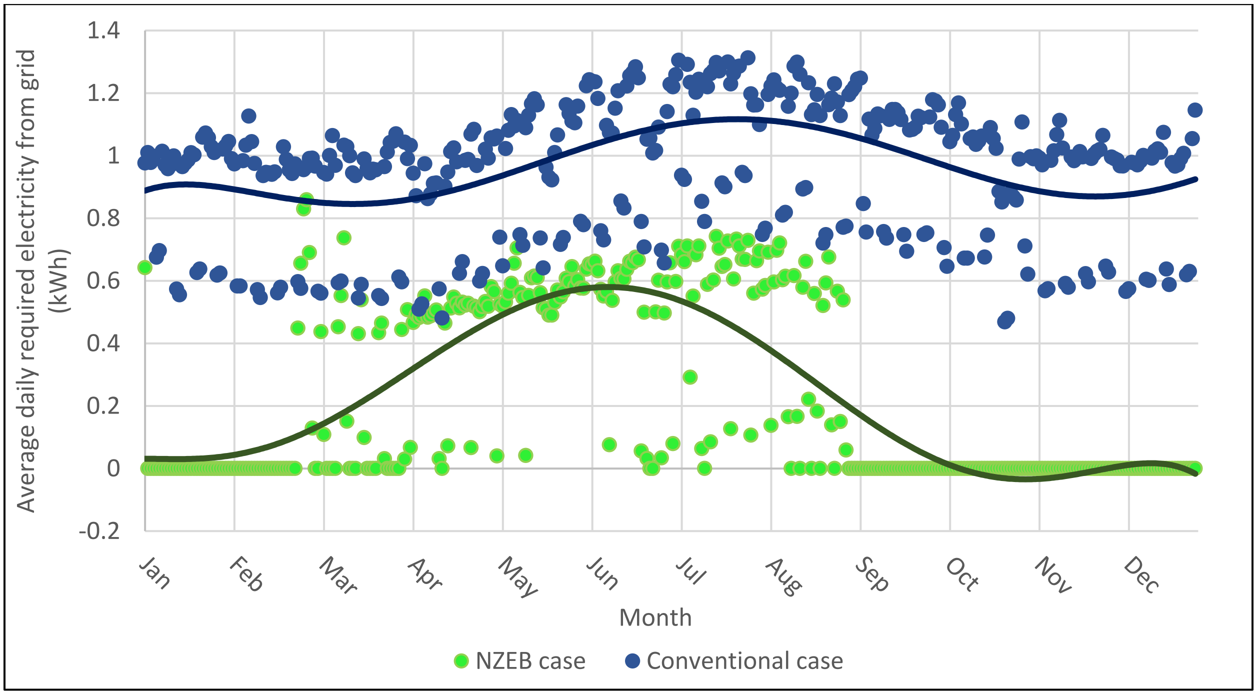

Figure 30.Comparison of daily required grid electricity for conventional and NZEB buildings

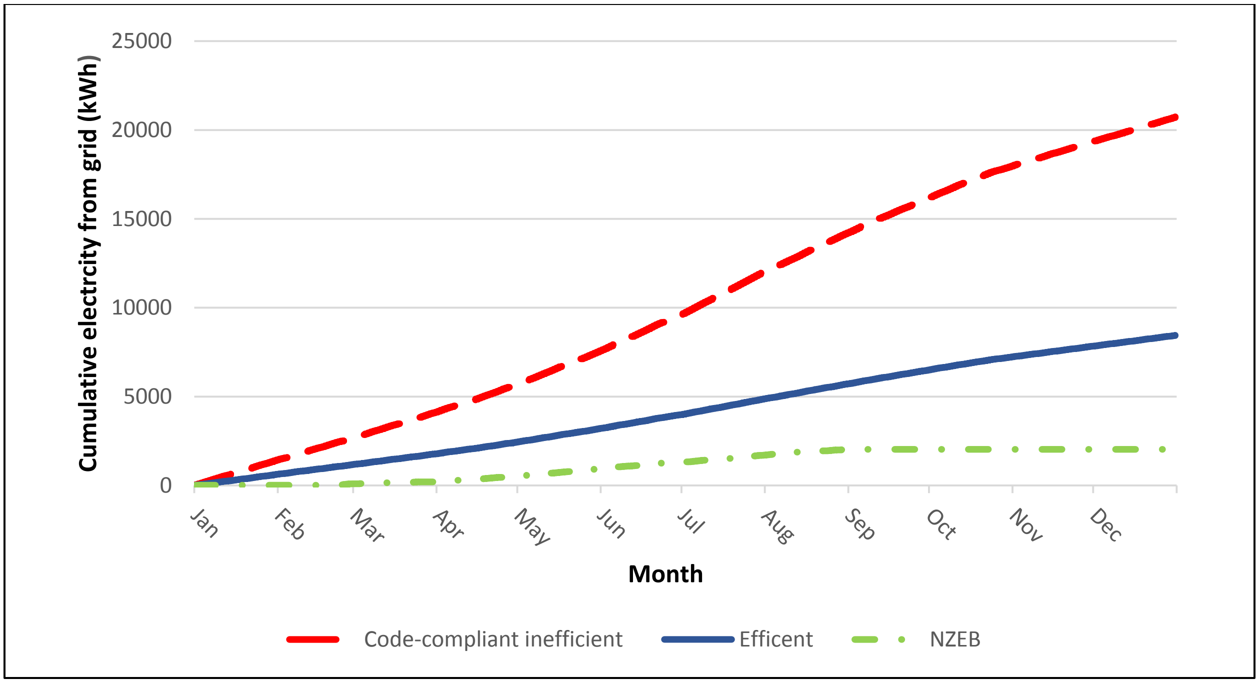

Figure 31. Comparison of required grid electricity for conventional and NZEB buildings

The above-mentioned 76% reduction in required electricity from the grid is not the only advantage of this system. As mentioned earlier, one of the goals of this system is to transfer excess electricity back to the grid whenever the total available electricity in the main battery and in the EV battery is more than sufficient for the building's energy demand. As seen in Figure 32, with the help of this system, it is possible to give up to 6,954 kWh in surplus energy back to the grid. This value is especially important when comparing the electricity costs for conventional and NZEB methods. As demonstrated in Figure 32, the hourly electricity that can be transferred to the grid is lower in the summer than in other times of the year due to the higher electricity consumption of the building, leaving less available electricity to be transferred to the grid. In this graph, the cumulative transferred electricity to the grid is also shown. As a result of implementing the abovementioned algorithm, it is possible to provide near 7000 kWh electricity to the grid by the end of the year, which can significantly reduce the cost of electricity for homeowners.

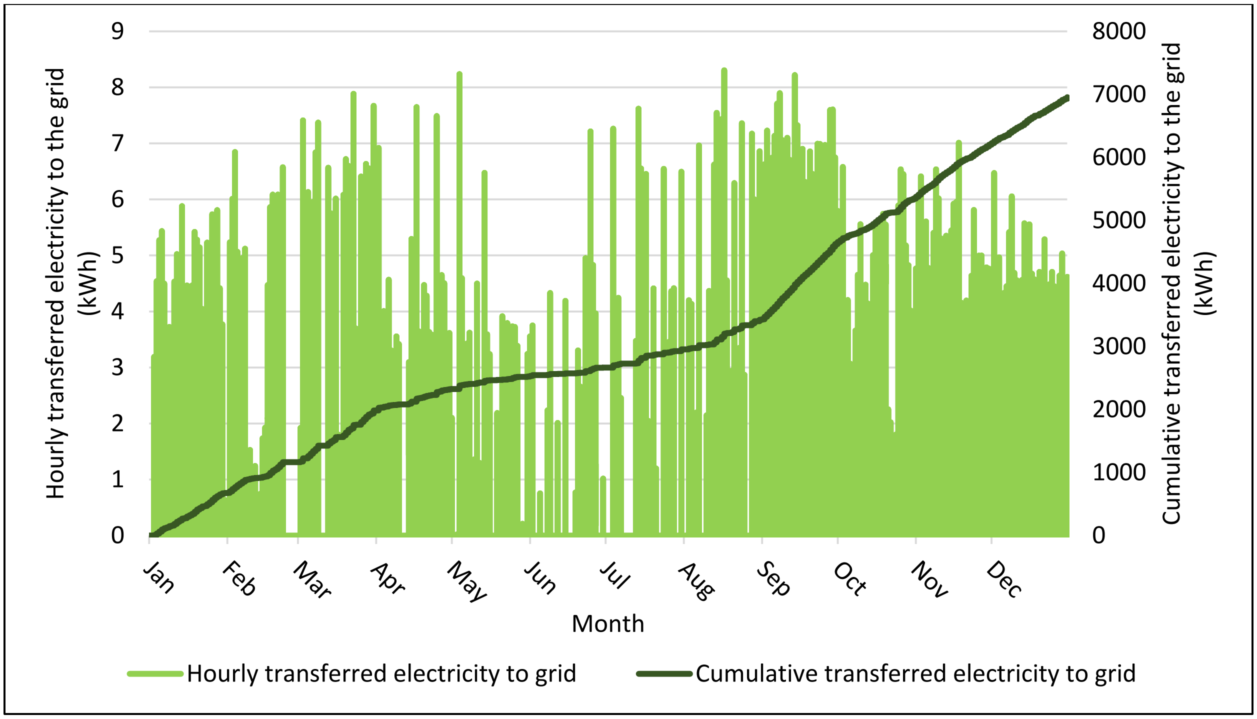

Figure 32. Monthly transfer of electricity to the grid

4.2.3 Environmental impacts

About 40% of the total U.S. energy consumption was used for residential and commercial buildings in 2015 [139], compared to 30% for the industrial sector and 29% for the transportation sector [140]. The increasing rate in the average building's energy consumption mostly comes from electricity consumption, such that the electricity share of primary energy use in the U.S. increased from 56% in 1980 to 72% in 2005 [141]. Moreover, coal (33%) and natural gas (33%) are both major energy sources and had the largest percent shares of total U.S electricity generation in 2015. Petroleum, with a contribution of 1%, is another type of fossil fuel that is burned to generate electricity in the U.S. [136]. Reducing the required electricity from the grid and relying on renewable energy sources can both play very important roles in reducing fossil fuel consumption, particularly for electricity generation. As the results of this study indicate, and as seen in Table 14, it is possible to significantly reduce the fossil fuel consumption with the help of solar energy and EV batteries. This system helps to reduce the amount of fossil fuel consumption by approximately 1.58 times on average, assuming that the energy mixture of Orlando consists solely of coal, natural gas, and/or petroleum. Negative values in Table 14 mean that, with the help of this system, it is possible to not only reduce the fossil fuel consumption for supplying electricity to the building down to zero, but also to giving electricity back to the grid on a yearly basis and thereby save on fossil fuel to be burned to generate electricity.

Another important topic when discussing environmental impacts is the subject of GHG emissions. The electricity sector includes power generation, transmission, and distribution, all of which involve large amounts of CO_2 emissions, to such a degree that the electricity sector was the largest source of U.S. CO_2 emissions in 2014, accounting for more than 30% of the total GHG emission rate in the U.S. [142].

Considering the CO_2 emission rates for different fossil fuels, it is also possible to measure the reduction of this factor from reducing electricity-based fossil fuel consumption. The results of this analysis are summarized in Table 14, where the CO_2 emissions are compared for conventional (grid-based) methods to supply electricity to the building and and for the corresponding NZEB methods. From Table 14, although the amount of natural gas burnt to supply electricity for the building is higher, the amount of CO_2 savings from using less coal is higher due to the carbon intense nature of coal burning comparing to natural gas and petroleum.

The key parameters required to calculate the fossil fuel savings and CO_2 emission reductions have been defined as shown in Table 12.

Table 12. Predefined parameters to calculate environmental impacts

Parameter	Value	Unit	Reference
Amount of coal burnt	0.00052	Short tons per kWh	[143]
Amount of natural gas burnt	0.01011	1000 Cubic feet per kWh	
Amount of petroleum burnt	0.00173	Barrels per kWh	
CO_2 emission factor (all types)	6.89551 E-4	Metric tons per kWh	[144]
Kilograms of CO_2 emission from coal	2,100.82	Short tons	[145]
Kilograms of CO_2 emission from natural gas	53.17	Mcf	
Kilograms of CO_2 emission from petroleum	14.7	Barrels	

The values mentioned in Table 12 above can vary depending on the efficiency or heat rate of the generator (or power plant) and on the heat content of the fuel [143]. The values used in this study are based on assumptions from the EIA [146] as summarized in Table 13.

Table 13. Assumptions for calculating fossil fuel consumption to generate electricity

Fuel	Power plant heat rate	Fuel heat content
Coal	10,080 Btu/kWh	19,420,000 Btu/Short ton
Natural Gas	10,408 Btu/kWh	1,029,000 Btu/ Mcf
Petroleum	10,156 Btu/kWh	5,867,946 Btu/Barrel

Table 14. Fossil fuel consumption comparisons between conventional and NZEB methods

Fossil fuel consumption and CO_2 emission rates	**Unit**	**Conventional method**	**NZEB method**
Coal burned	Shorttons	4.39	-2.56
Natural gas burned	Mcf	85.5	-49.8
Petroleum burned	Barrels	14.63	-8.52
Coal CO_2 emissions	Kg/shorttons	9,236	-5,378.4
Natural Gas CO_2 emissions	Ton/mcf	4,544.7	-2,646.5
Petroleum CO_2 emissions	Kg/barrel	215	-125.2
CO_2 emissions based on U.S. electricity mixture	Metric tons	5.83	-3.39

As clearly shown in Table 14 above, it is possible for a NZEB to reduce CO_2 emissions by a factor of up to 1.58 on average on a yearly basis. In reality, considering the electricity mixture of the U.S. and the CO_2 emissions for every 1 kWh of electricity generated, it is possible to reduce significantly reduce CO_2 emissions with the help of this system, as indicated in the results in Table 14.

4.2.4 Electricity Price

Recently, renewable energy sources and cutting-edge technologies capable of providing power to buildings have received a great deal of attention and increasing support from public authorities due to their predicted role in reducing the destructive environmental impacts of conventional energy sources [147]. In any effort to reduce reliance on fossil-fuel-based grid electricity and/or to move toward renewable energy sources and technologies such as V2H, costs and economic justification should be addressed as a top priority to encourage households to shift from conventional sources of energy to other sources of energy and technologies that can provide such unconventional power to their homes. The life cycle costs of renewable energy sources and V2H technology are beyond the scope of this study, but this study nevertheless seeks to investigate the effects of time rate pricing in different seasons of the year for reducing the amount of electricity received from the grid during on-peak hours in favor of receiving more electricity from the grid during off-peak hours, as well as the use of photovoltaic credits to encourage the generation of solar energy and the transfer of excess solar electricity to the grid. The data used in this study for this purpose was collected from the Orlando Utilities Commission (OUC) and is presented in Table 15.

Table 15. Time rate pricing [47]

	Summer (Apr 1st to Oct 31st)		**Winter (Nov 1st to Mar 31st)**	
	Hours	**Price (¢/kWh)**	**Hours**	**Price (¢/kWh)**
On-peak hours	13-18	5.936	7-10 & 18-21	4.447
Off-peak hours	20-11(next day)	3.759	10-18	2.886
Shoulder hours	11-13 & 18-20	4.527	21-7 (next day)	4.287
Non-fuel base charge	N/A	6.918	N/A	6.918
Photovoltaic production incentive	N/A	5	N/A	5

In the cost-related calculations for this study, two other factors are also used to calculate the total price of electricity for the NZEB design. The first factor is the purchase price of the electricity transferred to the grid, which the utility company will purchase at a price of 7.57 cents per kilowatt-hour (¢/kWh) [129], and the second factor is called the Photovoltaic Production Incentive, which is considered for every kWh of the solar energy generated through solar panels, regardless of the specific situation, if the generated energy is used to power the home or is sold to the grid at a price of 5 cents per kilowatt-hour (¢/kWh) [128]. After applying the above-mentioned rates for different times of the year and the electricity consumption of the building during different times of the year, the results were as shown in Figure 33 and Figure 34 below.

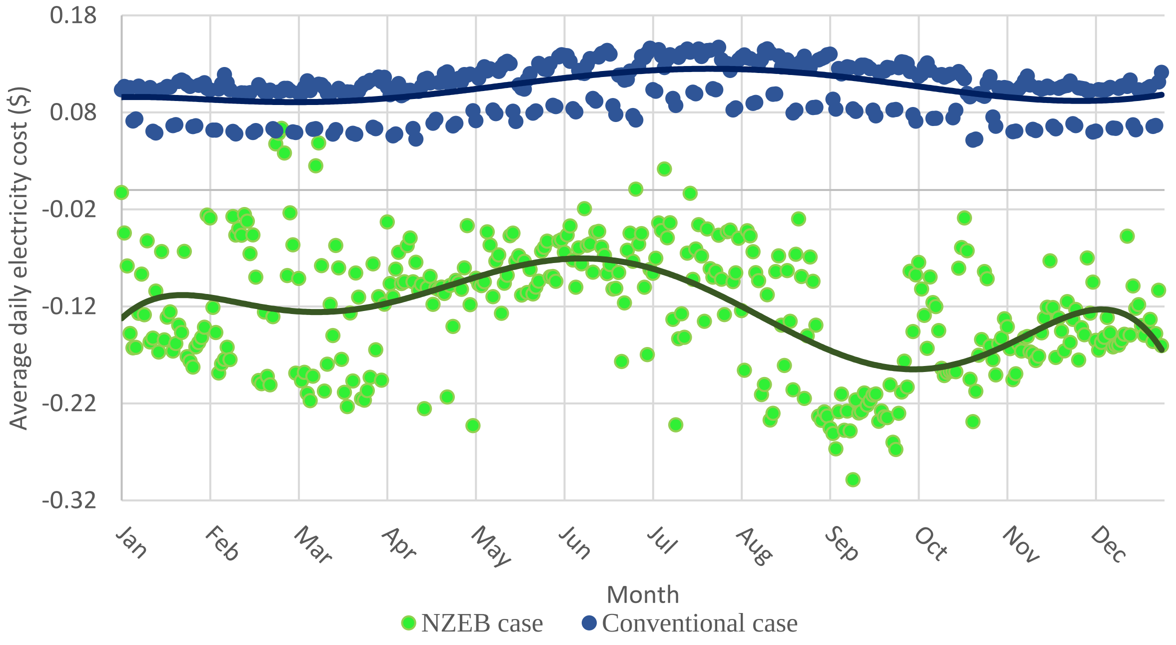

Figure 33. Hourly electricity cost comparison for conventional and NZEB methods

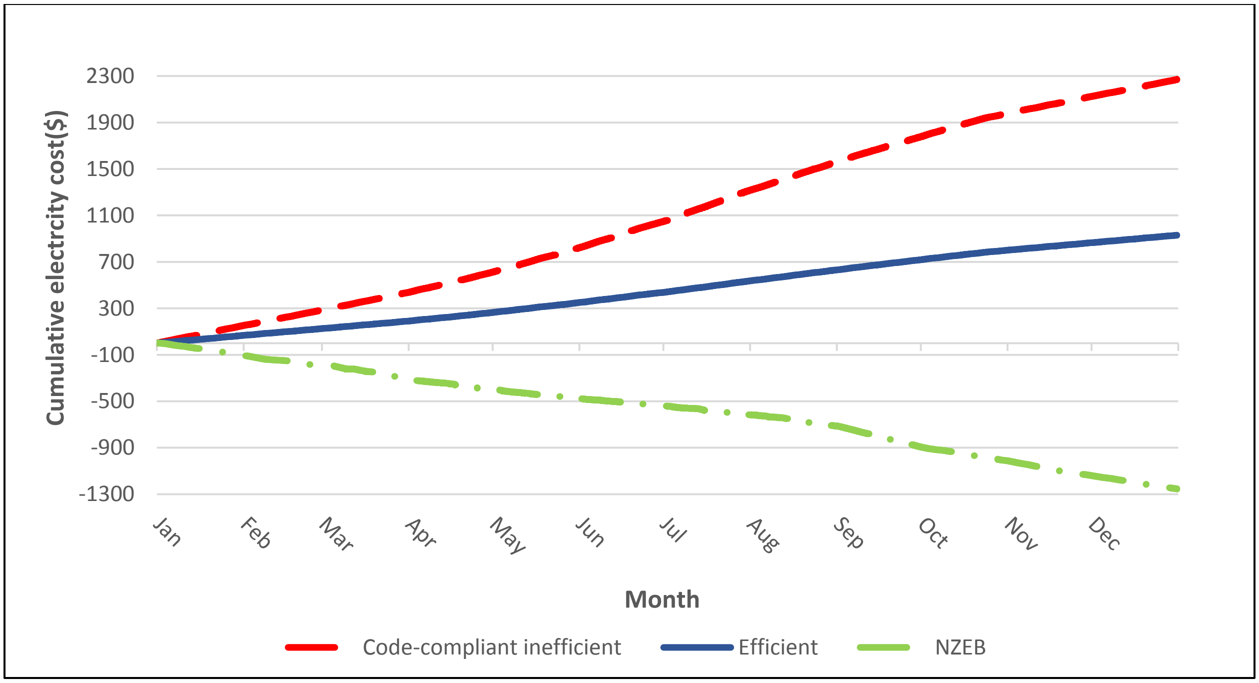

Figure 34. cumulative electricity cost comparison for conventional and NZEB methods

The hourly energy consumption graph shows the differences between the hourly electricity prices with the conventional and NZEB methods. As seen in Figure 33, the electricity consumption of the building is highest during the months of June, July, and August (when the electricity price is at its lowest negative value) because less energy can be transferred to the grid as previously shown in Figure 32. In order to more clearly illustrate the difference between the electricity prices, the cumulative electricity price has been graphed in Figure 34 for three separate cases: a code-compliant but inefficient system, an energy-efficient system, and a NZEB system. This figure shows that, with the help of the developed NZEB system, the electricity price drops by 155% compared to conventional methods.

4.2.5 Home-to-vehicle electricity

One of the goals of connecting EV power to buildings is to use the EV battery as a backup power source in case of an emergency or during a power outage. In addition, as discussed earlier, EV batteries can contribute to electricity price reductions by storing electricity during off-peak hours, when electricity prices are low, and then use the stored electricity during on-peak hours when electricity prices are higher. However, this system can work both ways if need be, meaning that the system is able to fully charge the EV as needed. In order to obtain the amount of electricity transferred to the EV, the amount of available charge in the EV battery is calculated for two separate times of the day (when the car reaches home at 5 PM and when the car leaves for work at 8 AM) as shown in Equation 1 below:

Transferred electricity to EV battery = EV available charge (t = 8) - EV available charge (t = 17) (Eq.1)

In this study, the amount of available charge in the EV battery depends on the state of charge (SOC). As the SOC increases, less electricity can be transferred to the EV battery, so more electricity will instead be stored in the main battery or transferred to the grid. This study shows that, with the help of this system, it is possible to provide the EV battery with 2,500 kWh of electricity per year. In this way, not only is the energy demand of the building adequately supplied during on-peak hours, but the EV always leaves the home fully charged every day.

Considering the average price of electricity in Florida, the savings from recharging the EV battery would be:

2500 kWh * 0.1134 $/kWh = $283.50

This amount is already considered in the savings calculations for the NZEB.

4.2.6 Validation and verification of ABM

The using of simulation models in problem solving and to aid in decision-making is rapidly increasing, and since the results of these models are constantly being used by developers and decision makers today, it is highly important to ensure that the model and its results are "correct" for such purposes [148]. The verification and validation (V&V) of such simulation models are therefore crucial for any simulation study because, without this step, there are no grounds on which to place any degree of confidence in the results of a particular study [149]. Despite all of the advantages and capabilities of ABM in modeling complicated problems, it should be noted that ABM generally belongs to a class of software referred to as " non-testable programs" [150]. Weyuker describes this class of software as "programs which were written in order to determine the answer in the first place. There would be no need to write such programs if the correct answer were known" [151]. That said, it is clear that ABM models are difficult to verify, especially in the absence of historical data. The most common ways to verify an ABM model are to refer to historical data, to compare the ABM model's results with mathematical model results, and to dock other simulations of the same phenomenon into the model [150]. In the case of this study, since the algorithm described above is designed to simulate a process that has never been tested before, neither there is no pre-existing mathematical formulation or any other model that fits the same purpose. Moreover, no historical data is available for such a system with which to verify the results of the ABM model. Considering all of the abovementioned points, this study instead tries to logically discuss why the developed model is correct for the purpose of the study, i.e. achieving a NZEB (validation), and then discuss how one can check whether or not the developed algorithm works perfectly (verification).

In order to develop a new plan to achieve NZEB, various tools and technologies should interact together to guarantee the feasibility of a project. In this study, different technologies required to develop such a system are available, including solar panels from which to draw electricity, V2H technology, storing renewable energy, net metering systems to measure the generated renewable energy, home-to-grid technology, vehicle-to-grid technology, and so on. On the other hand, many of the necessary tools to implement this system are already manufactured and available in the market, including EV batteries, power wall batteries to store renewable energy, solar panels, and so on. Since the feasibility of this system is therefore guaranteed, if this system can reduce the required electricity from the grid as discussed in the results, it can be concluded that the system works toward the goals established for the study, and the model is therefore deemed valid for this study. In order to verify the simulated model, the correctness of the system is tested by assigning extreme values to different key parameters to see whether or not the system still works as expected. In other words, based on the logic of the algorithm, the behavior of the system should make sense even when extreme conditions are simulated. Different sensitivity analyses have been performed for this purpose, and in each test, extreme values are assigned to the parameters as well as median values.

In the first sensitivity analysis, different values are assigned to the state-of-charge parameter (SOC), and the amount of electricity required from the grid is compared accordingly. In this case, it is expected that, as the state of charge increases, more electricity is available in the EV battery when it reaches home, and more contribution from the EV battery is therefore expected to supply the electricity demand of the building, while less electricity is required from either the grid or the main battery to recharge the EV battery. As the state of charge decreases, the amount of electricity to be drawn from grid increases as shown in Figure 35. This graph matches with our expectations for the behavior of the system.

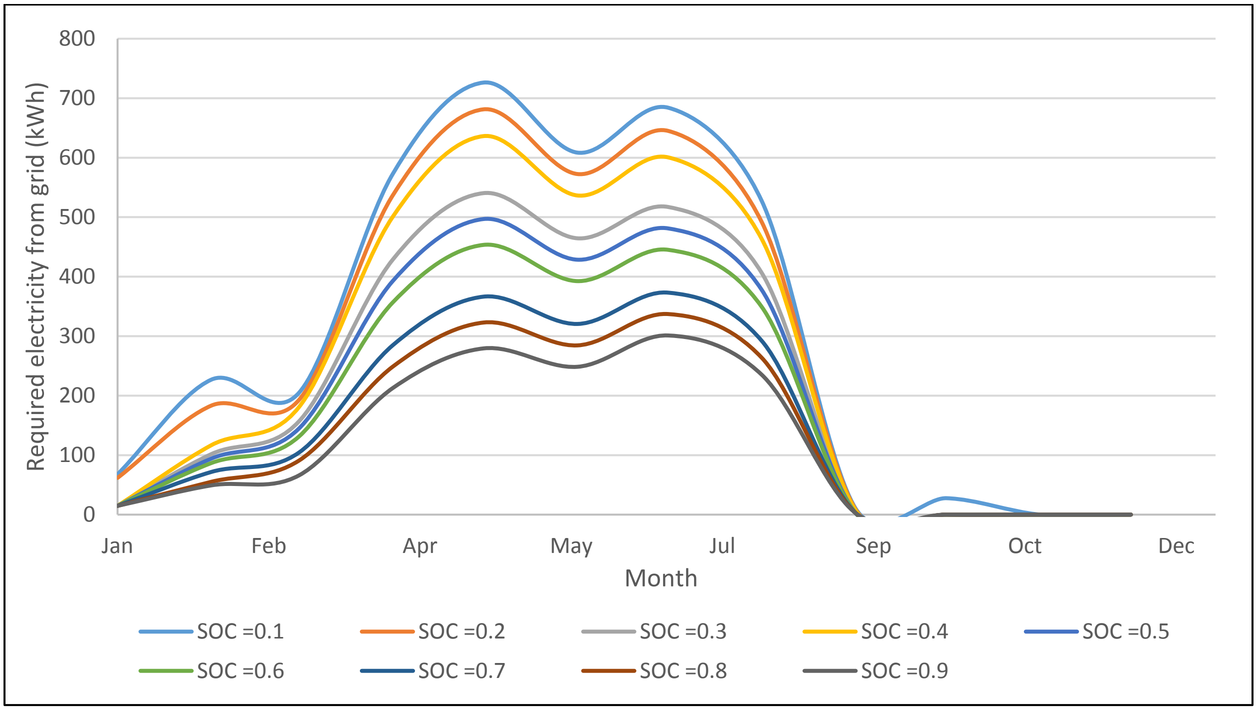

Figure 35. Sensitivity analysis, Monthly required electricity from the grid for different values of SOC

This Figure clearly shows that, as the state of charge increases from 0.1 to 0.9, the amount of required electricity from grid decreases.

The second sensitivity analysis investigates the effect of the main battery capacity (MBC) on the amount of electricity transferred to the grid. As previously discussed in Section 3.1.4, the developed algorithm requires the generated electricity to be stored in the main battery first, and then the surplus electricity (if any) is transferred to the grid. Based on this assumption, the higher the capacity of the main battery, the less surplus electricity is available to be transferred to the grid, because more electricity is required to fully charge the main battery. As seen in Figure 36, the results of the sensitivity analysis for the main battery show that, by increasing the MBC from 10 kWh to 100 kWh, the amount of electricity transferred to the grid is reduced significantly, dropping from 9,300 kWh to 5,150 kWh at the end of the year.

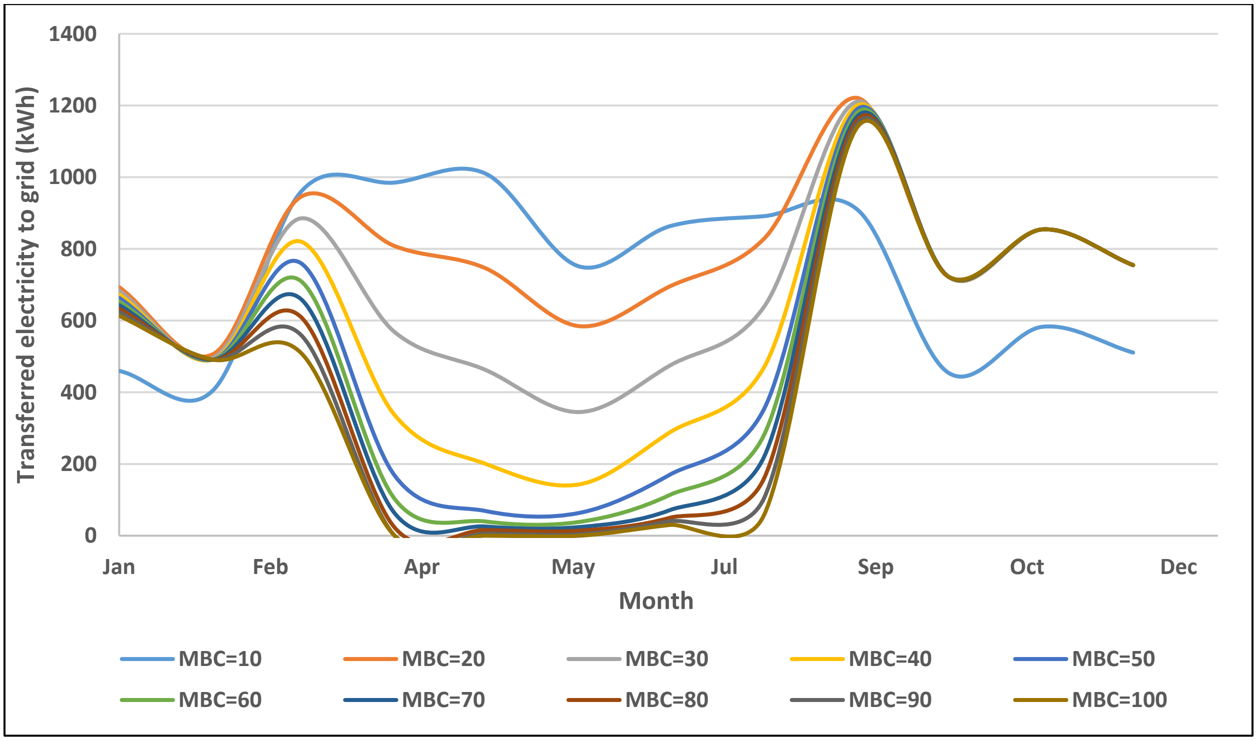

Figure 36. Sensitivity analysis, yearly electricity transfer rate to the grid for different main battery capacities

As explained earlier in this section, this kind of sensitivity analysis can be performed for different parameters in order to ensure that the results of the modeled algorithm match all reasonable expectations for the system’s behavior. In the other word, the results of these analyses should follow the logic of the algorithm, and in the case of this study, it can be concluded that the model does indeed follow the logic specified in the algorithm.

CHAPTER FIVE: REGIONAL INVESTIGATION

In the last phase of this study, an investigation on the implementation of this system in different climate regions of the U.S. is conducted. The two important parameters that mostly affect the results if the whole NZEB-EV system are investigated in more detail in this chapter. The first one is the weather conditions of the region in which the building is located. Weather conditions can greatly affect the results of the energy analysis thereby affecting the outcome the developed algorithm. In this regard, different climate regions of the U.S are considered for investigating the effect of weather situation on the system behavior.

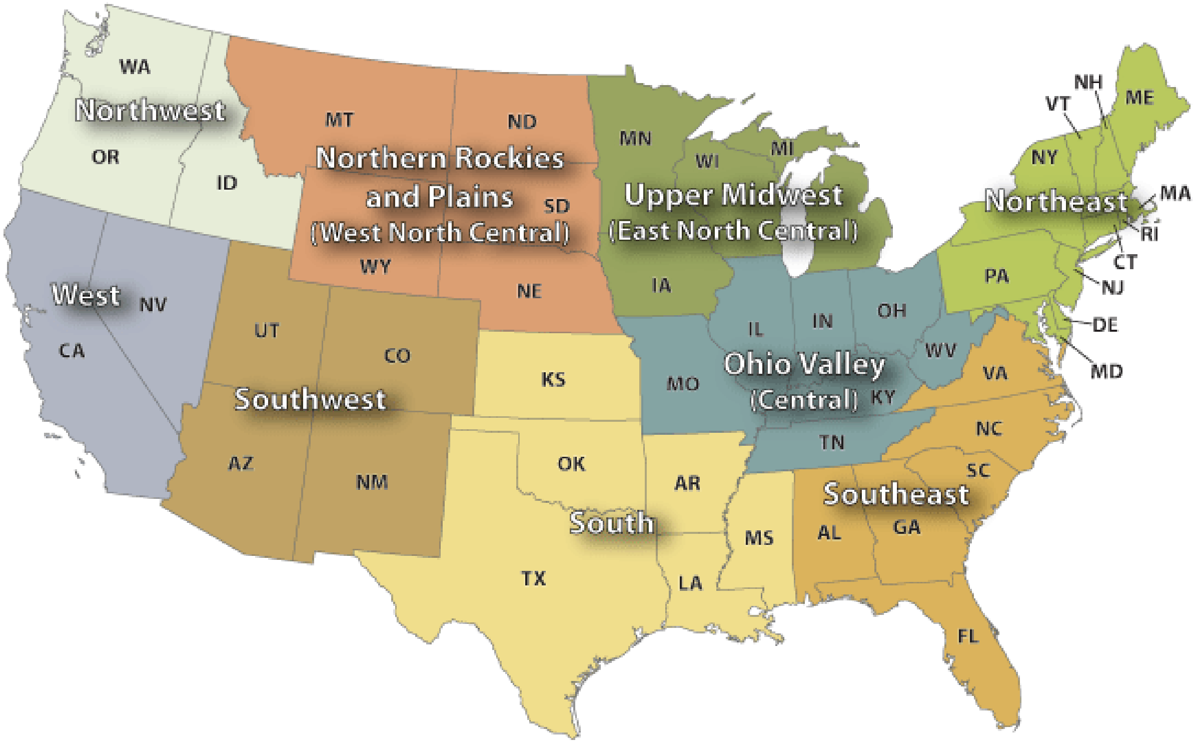

Figure 37. U.S climate regions [146]

For the purpose of analysis, one state has been selected in each climate region as a sample. The next step was to perform an energy analysis for a typical code compliant energy inefficient building and for a NZEB system under the developed algorithm. The nine selected states for nine climate regions are Oregon, California, Wyoming, Arizona, Minnesota, Indiana, Texas, Florida, and New York. In order to perform energy analyses, weather data file related to each region is used, and the following results were obtained.

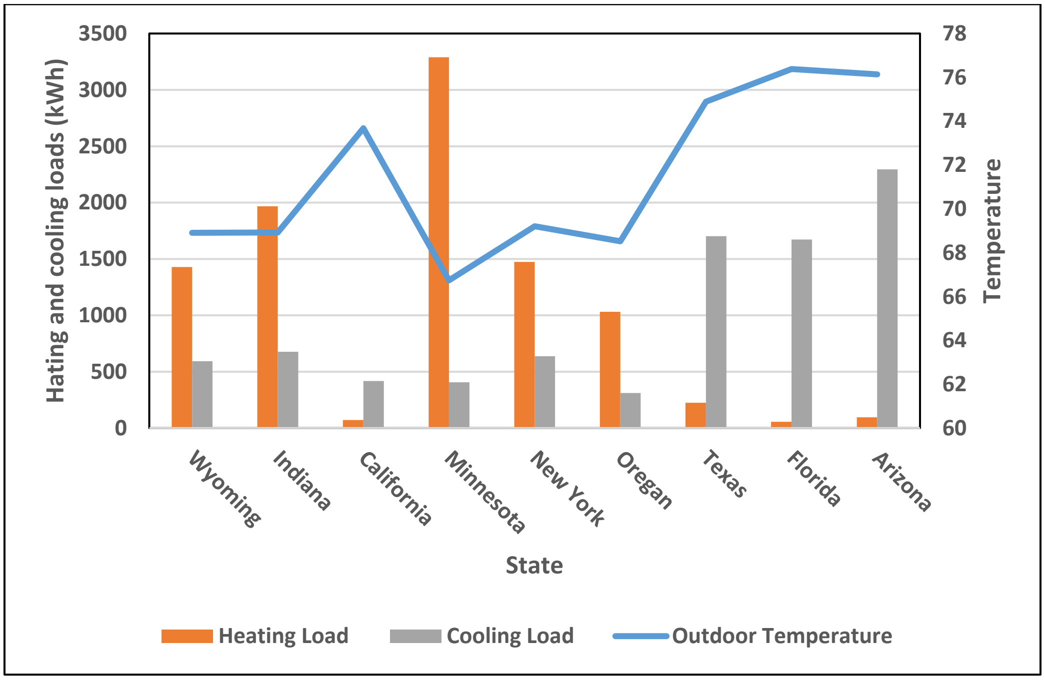

Figure 38. Energy analysis results, heating and cooling load vs outside temperature

The above graph shows a comparison between heating and cooling loads for different climate regions and different outside air temperatures. As can be seen, as the temperature goes higher in the hotter climates, cooling load increases and heating load decreases. For example, comparing Indiana and Texas, it is obvious that due to higher air temperature in Texas, heating load is negligible while in Indiana we can see an opposite trend. In some areas such as California, natural ventilation plays an important role in reducing HVAC load and that’s why heating and cooling loads are lower compared to other areas with the same temperature. The reason is that natural ventilation plays a very important role in reducing HVAC load in these areas. Another factor that can affect the behavior of the system is state of charge (SOC). It is already discussed how different values of SOC can change the outcomes of the model and at the same time the amount of generated solar energy plays a critical role in determining the amount of reduced required electricity from the grid. In this regard, it is tried to investigate the role of each of these parameters in reducing the reliance on grid electricity. Figure 39 and Figure 40 show the amount of reduced required electricity from grid versus solar energy generation and SOC for different states. The amount of SOC is highly dependent on driving behavior, traffic congestion and other roadway related parameters. In this study, SOC is considered as a function of travel time index. This means that as the travel time index increases, SOC decrease and vice versa [152].

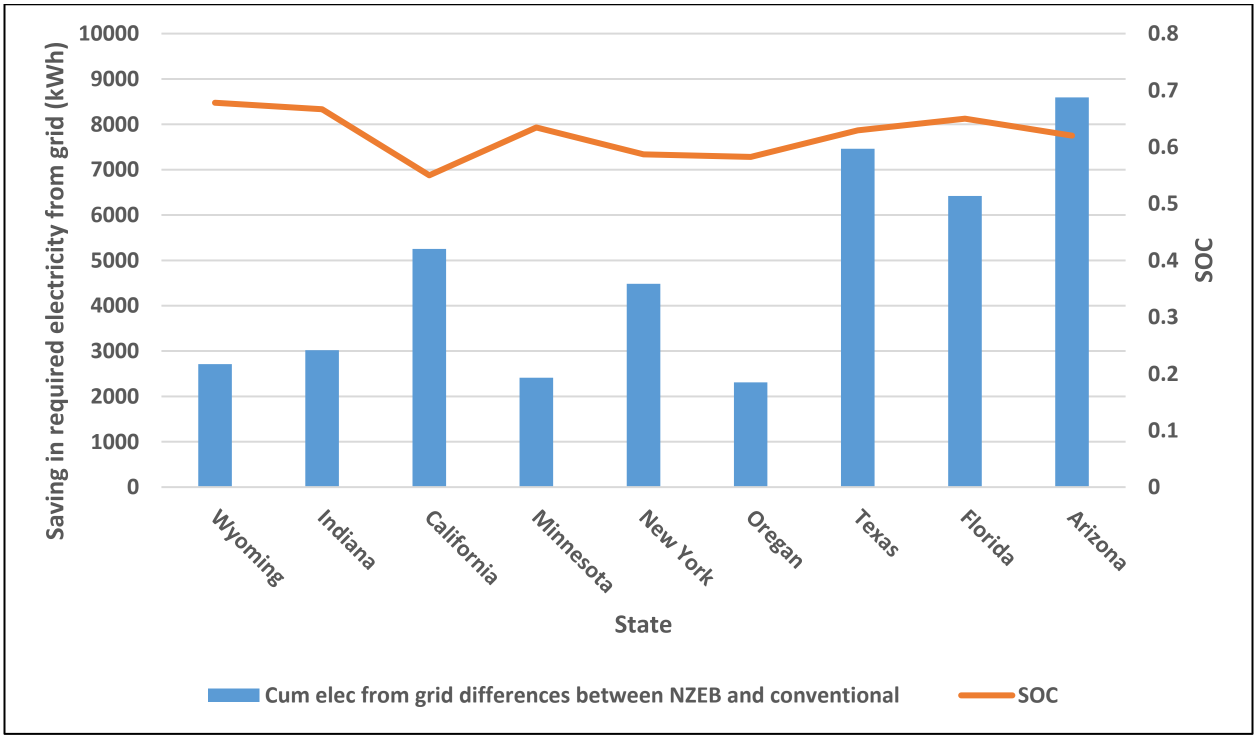

Figure 39. Amount of reduced required electricity from grid vs SOC for different states

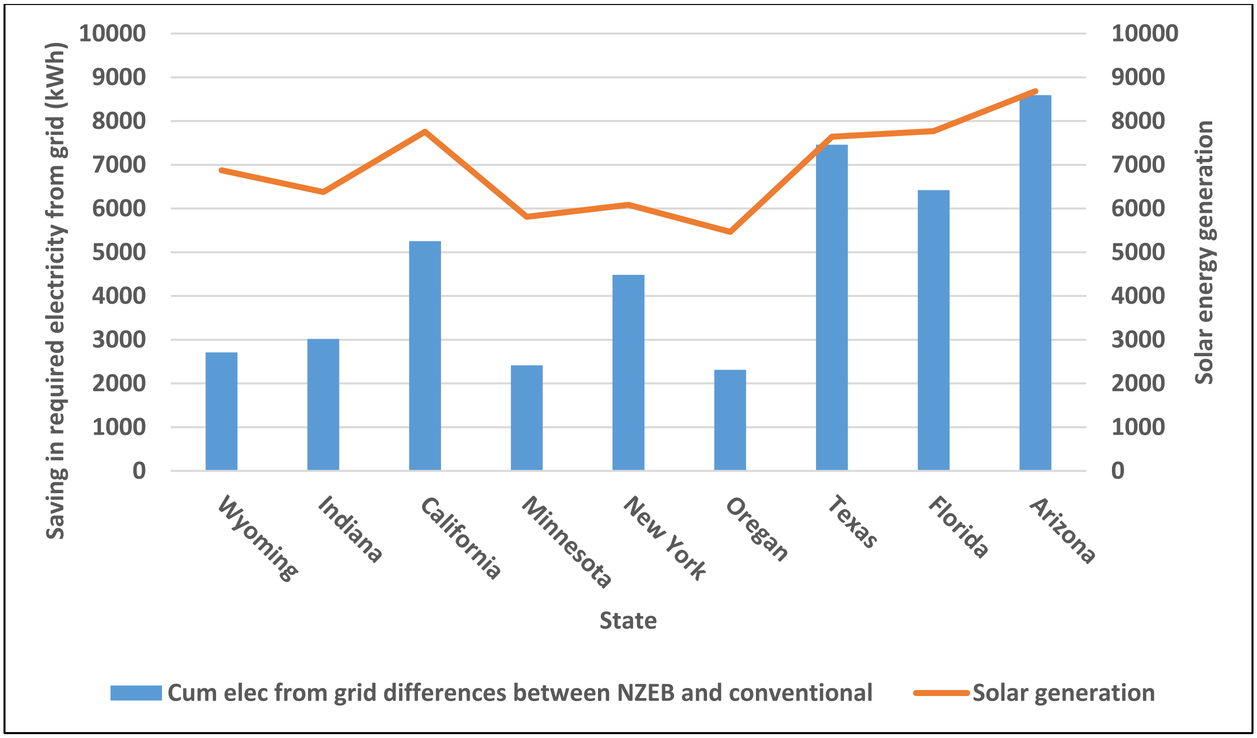

Figure 40. Amount of reduced required electricity from grid vs solar energy generation for different states

As can be seen in graphs above, the effect of generated solar energy has a highly significant effect on the amount of reduced electricity from grid. By looking at Figure 40, it is obvious that, in most areas, as the solar energy generation increases, the amount of saving in electricity also increases. As can be seen, more savings in purchased electricity from the grid is made in Arizona than in other states because more solar energy is available in this region.

For calculating the cost of purchased electricity from the grid, a utility company that provides service to that specific area has been selected and the proposed rates of electricity of that company has been used as a basis for cost related calculations. The rate used in this study are based on different real pricing strategies employed by different utility companies nationwide. Some of these rates are illustrated in Figure 47as an example.

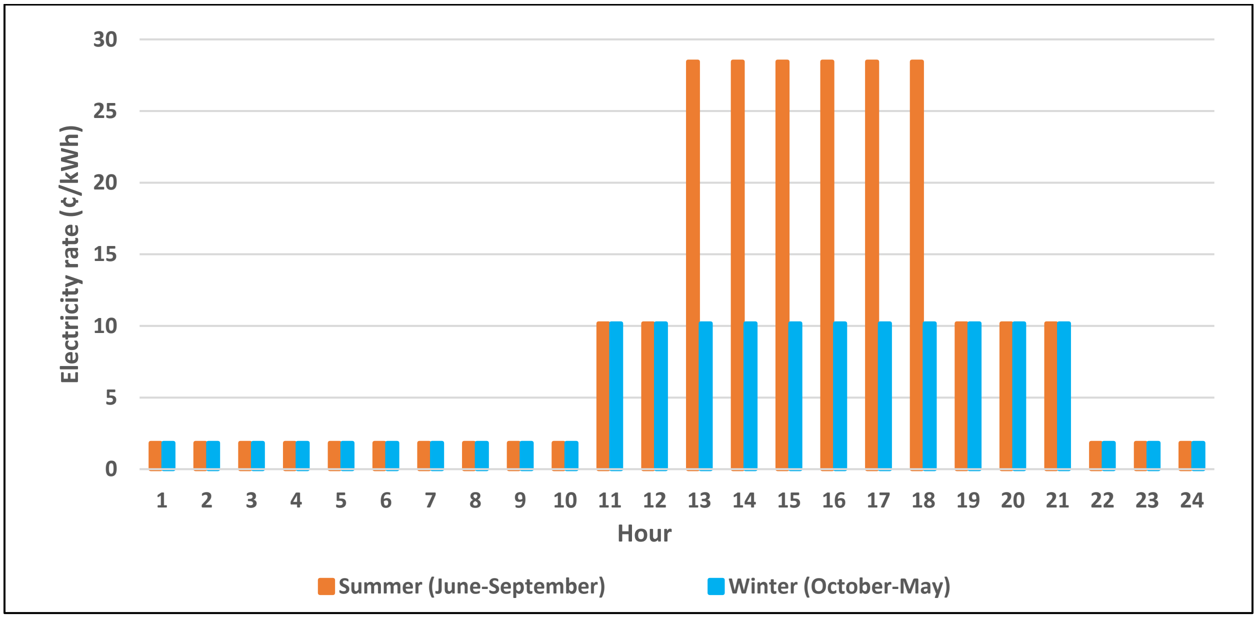

Figure 41. Time rate pricing , New York

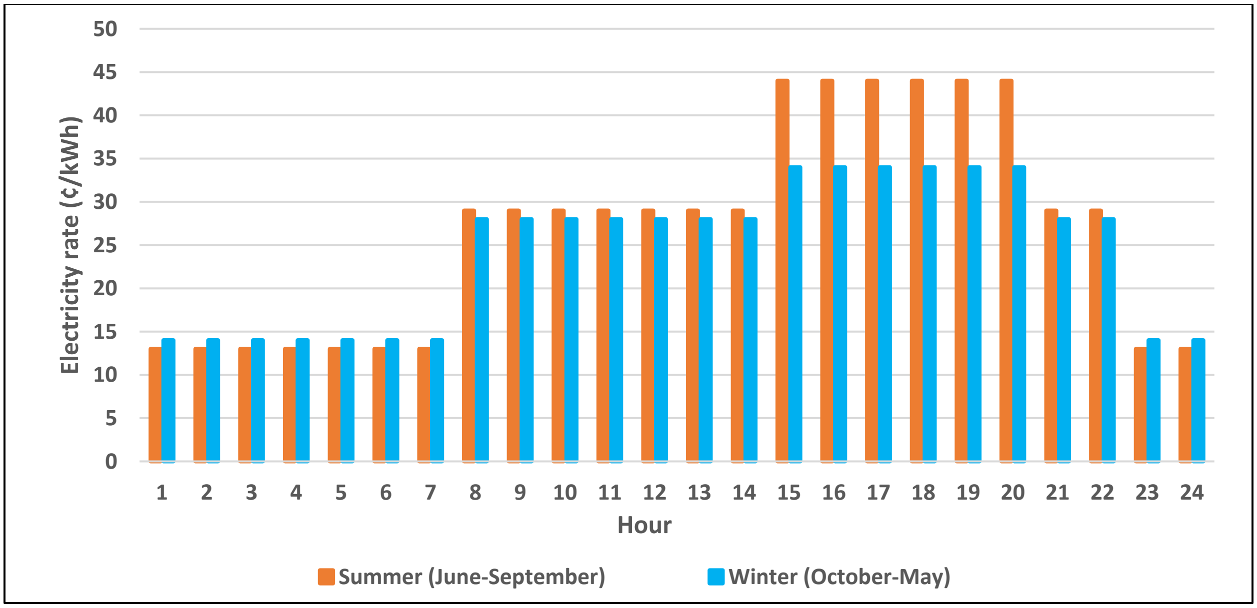

Figure 42. Time rate pricing , California

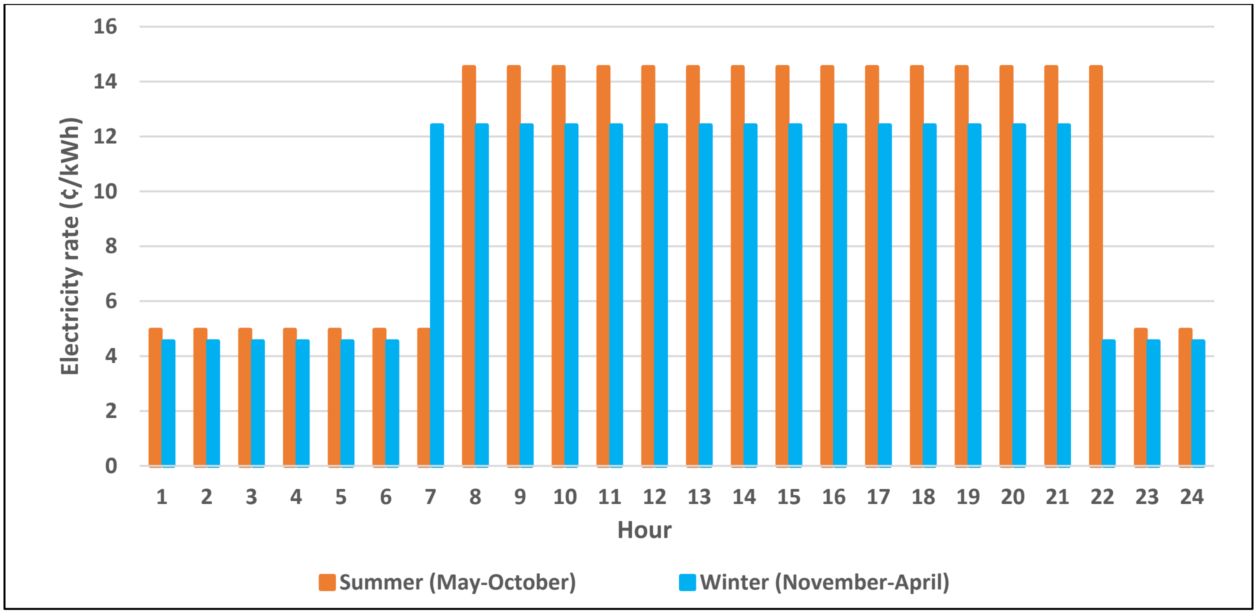

Figure 43. Time rate pricing , Wyoming

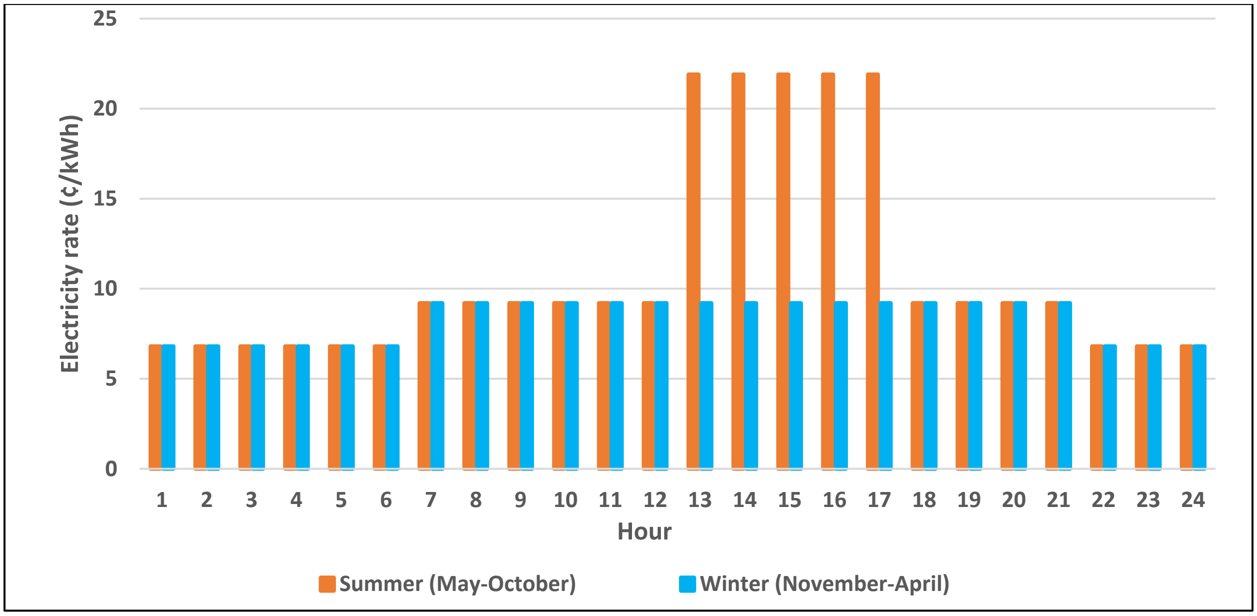

Figure 44.Time rate pricing , Texas

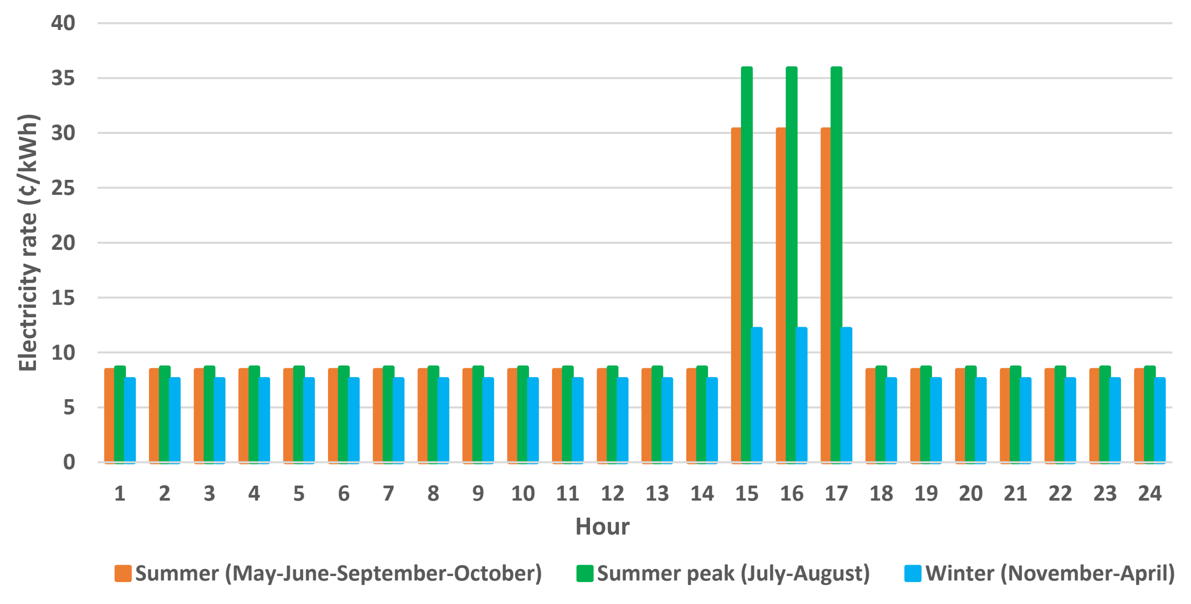

Figure 45. Time rate pricing , Arizona

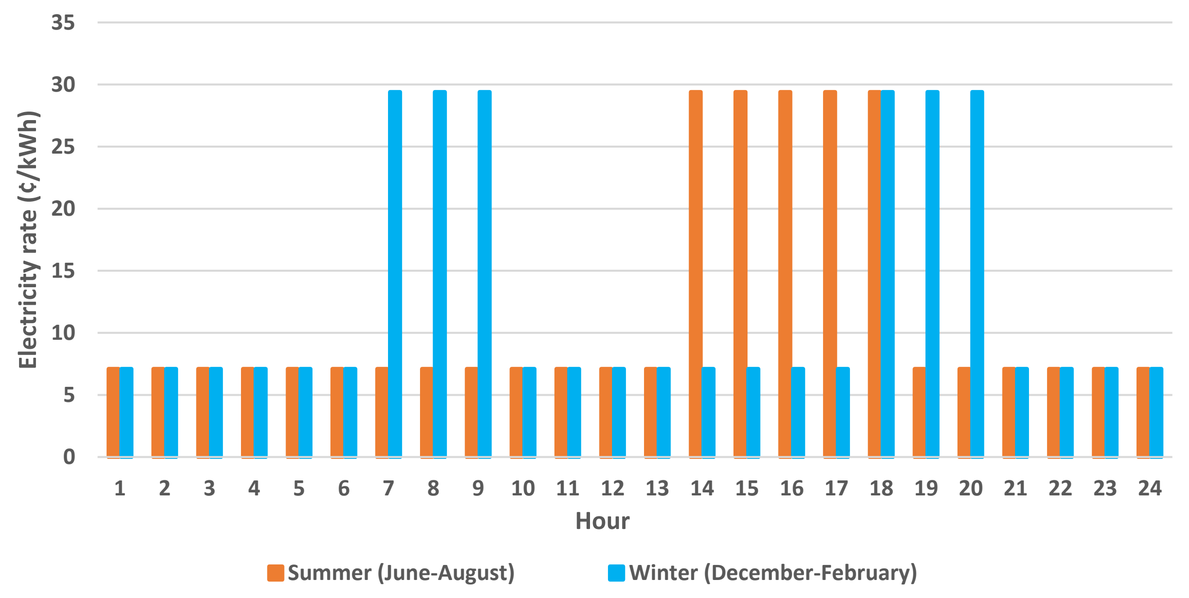

Figure 46. Time rate pricing , Indiana

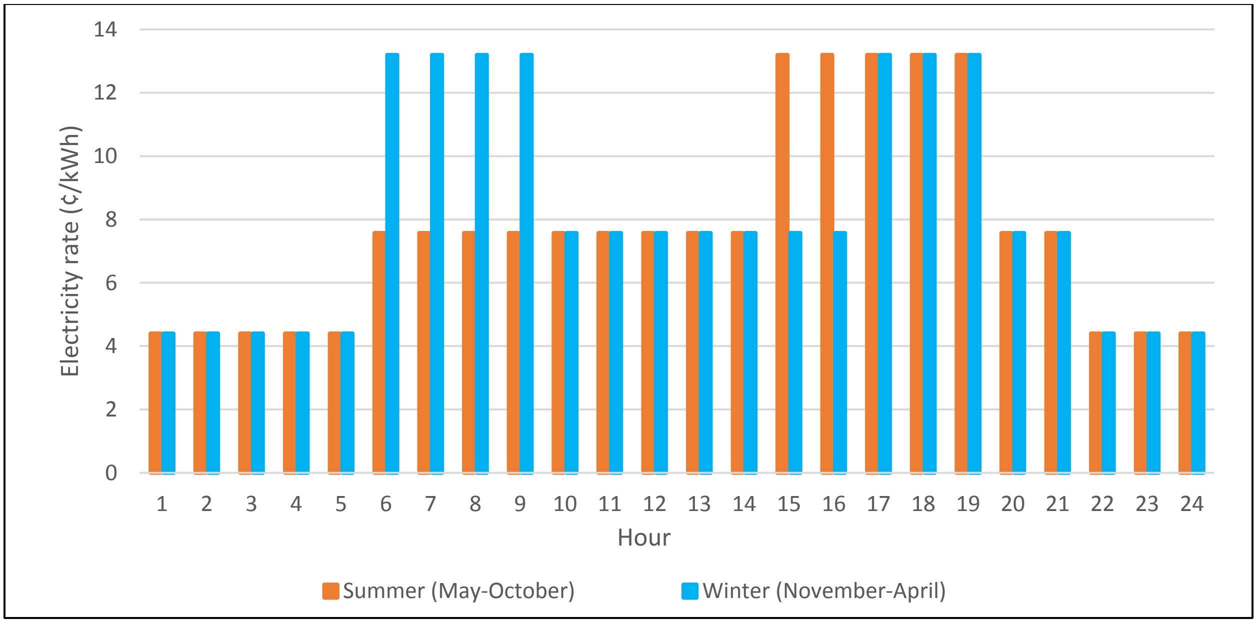

Figure 47. Time rate pricing, Oregon

After applying the above mentioned rates, the results of the cost calculation can be seen in Figure 42 below. The results of this study show that financial incentives and pricing strategies play vital roles in succeeding in encouraging homeowners to implement this system and move toward NZEB. As an example, in the two cases of California and Texas, it is obvious that although the amount of reduction in kilowatt hours of purchased electricity from the grid is higher in Texas, more monetary savings have been made in California due to appropriate pricing strategies.

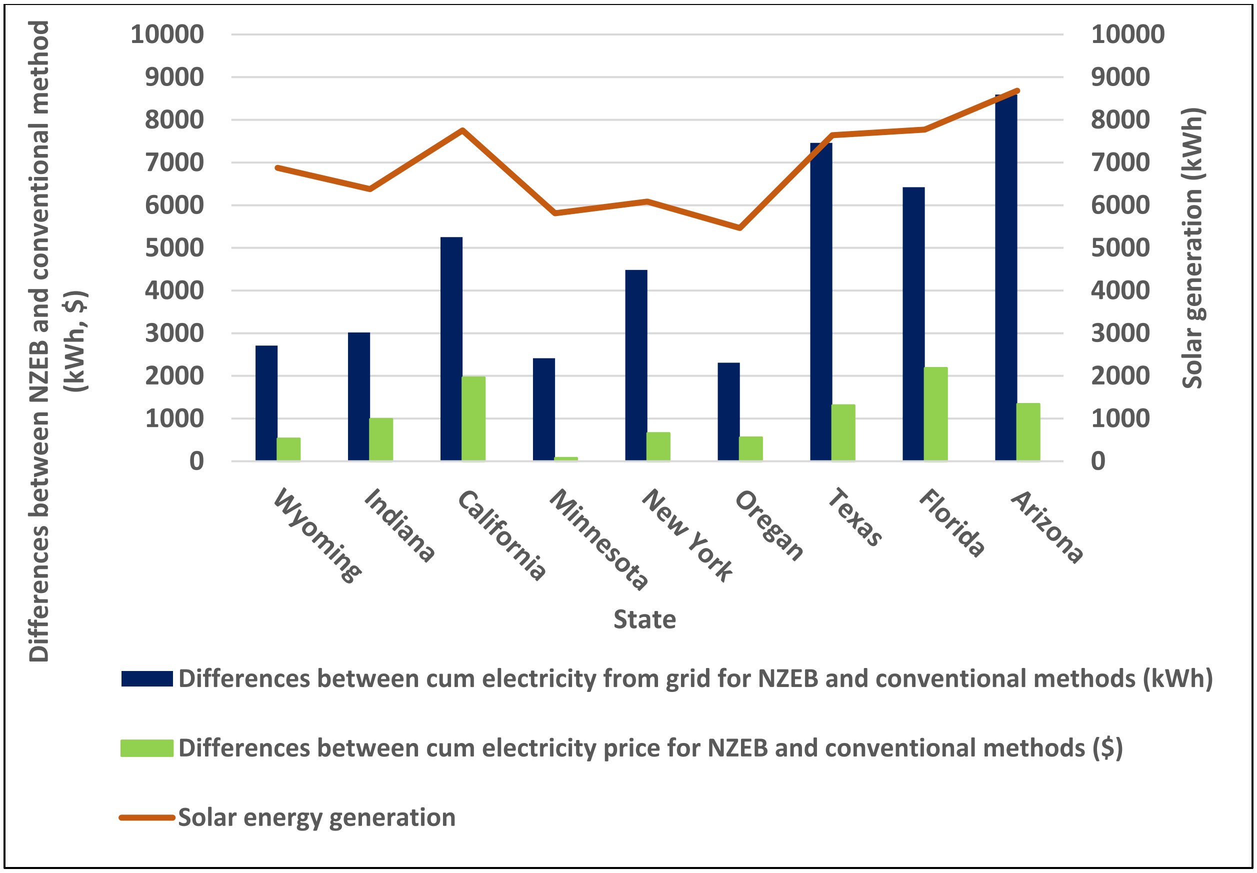

Figure 48. Electricity and monetary value of reducing reliance on grid electricity

CHAPTER SIX: CONCLUSION

This study attempted to investigate the role of EVs and renewable energy sources (e.g., solar power) as potential features in a net-zero-energy building (NZEB). The main parts of the system analyzed in this study included solar panels for generating electricity, a main battery that interacts with these solar panels, an EV, and the main power grid. Using an inverter, the generated solar power was stored in the main battery while the EV contributed to the overall system by providing electricity during on-peak hours and receiving electricity from the main battery and/or from the grid during off-peak hours.

This research tried to distinguish itself from previous works done in this field by incorporating EV batteries as a source of electricity that can supply power to the building rather than merely relying on renewable energy sources such as solar panels or wind turbines. Another breakthrough of this study is related to the developed algorithm in which different sources of electricity including EV battery, main battery, solar panels, and grid power can contribute in supplying electricity to the grid.

The mechanics of the system as a whole were based on a unique algorithm as described in Chapter 3 of this study, which assigned the energy sources to be used in the NZEB during any given hour of the day.

Two models have been used to implement the developed algorithm. The first model (NZEB-VBA) is developed in a visual basic programming environment, mainly focusing on calculating the overall results of applying this system. This model can be a useful tool for decision makers to see the savings through integrating renewable energies and EV to the building’s energy supply system of the building. Although this model enables us to instantly see the results of the analysis, it lacks the ability to track the behavior of different components of the system with real-time data, a key factor in encouraging homeowners to apply for this system. Considering this abovementioned limitation with NZEB-VBA model, the second model is built upon the first model with the same logic but in a different environment. The second model (NZEB-ABM) is developed in an Anylogic environment through an agent-based modeling simulation method. Agent-based modeling is an effective approach to model the dynamic interaction of different agents that are in interaction with other agents. This modeling approach is appropriate for cases where events happen in discrete steps. In this study, the data regarding energy consumption of the building, renewable generation, and EV connectivity is reported on an hourly basis, so each hour can be considered as an event. Different variables of the system change hourly in discrete events. Once the model receives the input data, the developed algorithm determines the sources of energy for the building.

Both developed models can be considered as a test bed to test different scenarios. After performing an energy analysis, the results can be used by models to analyze the imported data. In this dissertation, two case studies were investigated. Both cases are located in Orlando, FL. In order to perform an energy analysis, an Energyplus database has been used. The results of the energy analysis were exported to both models for further analysis. The results of the first case indicates that, with the help of this system, it is possible to reduce the amount of electricity required from the grid by up to 68% on average. The monetary value of reducing this grid reliance was also evaluated, and the evaluation showed that the resulting electricity bill can be reduced by up to 62% without considering any of the various incentives and credits offered by different utility companies and government organizations. When these credits and incentives are taken into account, the resulting overall savings can increase drastically to as much as 2.83 times on average. In fact, throughout the year, the net electricity price when credits are included is negative, representing a net profit to customers from selling electricity to the grid. For the second case study, when comparing the amount of electricity required from the grid for two conventional building designs and a NZEB design, it becomes apparent that the NZEB system can significantly reduce the reliance of the building on grid electricity by up to 76%. Consequently, it is also possible to reduce fossil fuel consumption and thus reduce CO_2 emissions to the atmosphere from the residential sector; based on the results of this study, it is possible to reduce these CO_2 emissions by as much as 1.58 times.

Efforts in order to decrease the carbon dioxide emission rate in cities have been effective but not enough. Besides controlling the CO_2 emission rate, there is still additional possibility to remove atmospheric CO_2 by sequestering it within urban area [153,154]. In building sector, not only by performing energy analysis and selecting the best design variables which are able to minimize the energy consumption of the building and minimizing the carbon dioxide emission of the building at the same time, but there are still chances to contribute more in reducing the amount of CO_2 in atmosphere by increasing the green space of the buildings or even having vegetable gardens. In order to test the effect of these supplementary activities, different databases should get involved in this simulation process. Using different tools provided by National Renewable Energy Laboratory or U.S forest service, it is possible to capture the effect of having green spaces or vegetable gardens on carbon sequestration of the building ecosystem. In future studies, it will be tried to include the surrounding ecosystem in the analysis regarding CO_2 emission calculations.

In the last phase of these analyses, several sensitivity analyses were performed to investigate the effect of the different modeled parameters (specifically the capacity of the main battery and the EV battery's state-of-charge value) on the overall performance of the system. Theses sensitivity analyses were used in the first place to see the ability of developed models to test different scenarios. Later, abovementioned sensitivity analyses were used to verify the accuracy of developed algorithms.

Finally, a regional study was made at the end to investigate the effect of weather condition, driving behavior and traffic congestion, and different pricing strategies on the outcome of these analyses. The results of this analysis indicates that the amount of solar energy generation is more significant than other parameters such as SOC. Also, it is observed how different pricing strategies can affect the amount of savings in implementing this system.

It is worth noting that this study was an attempt to apply V2H technology and solar power to a possible NZEB scenario; the results of this analysis showed that the net cost of electricity is negative by the end of the year, which can be interpreted as a net revenue for homeowners, but it should also be noted that having an energy-efficient building and installing solar panels can significantly increase the total capital cost. Even though the cost of solar panel installation has reduced noticeably in recent years, such costs should still be included in any complete life cycle cost analysis. Nevertheless, the significant reduction in electricity cost shows that this research can be used as a starting point for future efforts to design a NZEB. This study also attempted to discuss and present the potential feasibility of this system by developing an algorithm that can connect the different components of the system (the EV battery, the main battery, the power grid, and the building itself) although investigating the life cycle cost of the building and the related technical aspects were both beyond the scope of this study. Investigating the lifetime economic savings of this system is beyond the scope of this study. Due to the broadness of the borders in life cycle cost analysis, a separate study is required to fully investigate the life cycle cost and payback period of discussed models.

In future research, different pricing ranges will be tested using an Agent Based Modeling (ABM) approach where, by applying different pricing scenarios, the life cycle cost of the system and the payback period will be simulated in a real-time analysis. Moreover, more focus will be given to a life cycle cost comparison between a standard code-compliant building and a NZEB by considering the payback period of increased costs incurred from making the system more energy-efficient and from the integration of photovoltaic solar panels into the building's energy portfolio.

APPENDIX: ACRONYM LIST

NZEB	Net zero energy building
EV	Electric vehicle
ABM	Agent based modeling
V2G	Vehicle to grid
V2H	Vehicle to home
GHG	Greenhouse gas
EPA	Environmental Protection Agency
HVAC	Heating, ventilation and air conditioning
PV	photovoltaic

REFERENCES

[1] U.S. Department of Energy, Buildings Share of U.S. Primary Energy Consumption, 2012.

[2] U.S. Department of Energy, Energy Efficiency Trends in Residential and Commercial Buildings, 2008.

[3] Department of Energy, EIA Data: 2011 United States Energy Consumption by Sector and Source, Dep. Energy. (2011). https://catalog.data.gov/dataset/eia-data-2011-united-states-energy-consumption-by-sector-and-source-ae5c0/resource/f0dcf709-a782-481b-b1f9-4b39c4638b40.

[4] U.S. Energy Information Administration (EIA), Today in Energy, EIA. (2016). http://www.eia.gov/todayinenergy/detail.cfm?id=21072.

[5] U.S Department of Energy, Energy Department Invests $19 Million to Improve Efficiency of Nation's Buildings, (2016). http://energy.gov/articles/energy-department-invests-19-million-improve-efficiency-nation-s-buildings.

[6] I. Sartori, A.G. Hestnes, Energy use in the life cycle of conventional and low-energy buildings: A review article, Energy Build. 39 (2007) 249–257.

[7] C. Diakaki, E. Grigoroudis, D. Kolokotsa, Towards a multi-objective optimization approach for improving energy efficiency in buildings, Energy Build. 40 (2008) 1747–1754.

[8] Center for Sustainable Systems, U.S. Renewable Energy Factsheet, 2016.

[9] R.E.H. Sims, H.-H. Rogner, K. Gregory, Carbon emission and mitigation cost comparisons between fossil fuel, nuclear and renewable energy resources for electricity generation, Energy Policy. 31 (2003) 1315–1326.

[10] W. Leontief, Theoretical Assumptions and Nonobserved Facts, Am. Econ. Rev. 61 (1971) 1–7. doi:10.1126/science.151.3712.867-a.

[11] C. Reinhart, F, J. Mardaljevic, Z. Rogers, Dynamic Daylight Performance Metrics for Sustainable Building Design, J. Illum. Eng. Soc. North Am. 3 (2013) 7–31.

doi:10.1582/LEUKOS.2006.03.01.001.

[12] J.C. Vischer, Towards an Environmental Psychology of Workspace: How People are Affected by Environments for Work, Archit. Sci. Rev. 51 (2008) 97–108. doi:10.3763/asre.2008.5114.

[13] C. Scheuer, G. a Keoleian, P. Reppe, Life cycle energy and environmental performance of a new university building: modeling challenges and design implications, Elsevier. 35 (2003) 1049–1064. doi:10.1016/S0378-7788(03)00066-5.

[14] G.A. Blengini, T. Di Carlo, The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings, Energy Build. 42 (2010) 869–880. doi:10.1016/j.enbuild.2009.12.009.

[15] B. Golestani, B. Nam, M. Noori, J. An, O. Tatari, An optimum selection strategy of reflective cracking mitigation methods for an asphalt concrete overlay over flexible pavements, Int. J. Pavement Eng. (2016) 1–14.

[16] P. Lombard, L. José Ortiz, P. Christine, A review on buildings energy consumption information, Energy Build. (2008).

[17] L. Brookes, Energy efficiency fallacies revisited, Energy Policy. 28 (2000) 355–366.

[18] O.P. Akadiri, Development of a multi-criteria approach for the selection of sustainable materials for building projects, 2011. http://wlv.openrepository.com/wlv/bitstream/2436/129918/1/Akadiri_PhD thesis.pdf.

[19] U.S. Department of state, 2 014 Car, United States climate action report, 2014.

[20] U.S. Department of Energy, Building America: Bringing Building Innovations to Market, DOE. (2015). http://energy.gov/eere/buildings/building-america-bringing-building-innovations-market (accessed March 4, 2016).

[21] R. Hendron, C. Engebrecht, Building America house simulation protocols, U.S Department of Energy, 2010. doi:10.1017/CBO9781107415324.004.

[22] U.S.D. of Energy, Home Energy Score Research and Background, DOE. (2015). http://energy.gov/eere/buildings/home-energy-score-research-and-background (accessed March 4, 2016).

[23] R. Brown, C. Webber, J.G. Koomey, Status and future directions of the ENERGY STAR program, Energy. 27 (2002) 505–520.

[24] U.S. Department of Energy, For Contractors : ENERGY STAR, (2014). https://www.energystar.gov/index.cfm?c=home_improvement.hpwes_for_contractors (accessed April 1, 2016).

[25] M.C. Sanchez, R.E. Brown, C. Webber, G.K. Homan, Savings estimates for the United States Environmental Protection Agency's ENERGY STAR voluntary product labeling program, Energy Policy. 36 (2008) 2098–2108.

[26] T. Tsoutsos, Supporting schemes for renewable energy sources and their impact on reducing the emissions of greenhouse gases in Greece, Renew. Sustain. Energy Rev. (2008).

[27] U.S. Department of Energy, DOE Releases Common Definition for Zero Energy Buildings, Campuses, and Communities | Department of Energy, (2015). http://energy.gov/eere/buildings/articles/doe-releases-common-definition-zero-energy-buildings-campuses-and (accessed March 14, 2016).

[28] I. Sartori, A. Napolitano, K. Voss, Net zero energy buildings: A consistent definition framework, Energy Build. (2012).

[29] S. Mekhilef, R. Saidur, A. Safari, A review on solar energy use in industries, Renew. Sustain. Energy Rev. 15 (2011) 1777–1790. doi:http://dx.doi.org/10.1016/j.rser.2010.12.018.

[30] L. Mitchell, Z. Radu, Life cycle cost and energy analysis of a Net Zero Energy House with solar combisystem, Appl. Energy. (2011).

[31] E. Musall, T. Weiss, K. Voss, A. Lenoir, Net Zero Energy Solar Buildings: An Overview and Analysis on Worldwide Building Projects, EuroSun Conf. Graz 2010. (2010) 7–8.

[32] P. Kenny, Hernandez, Patxi, From net energy to zero energy buildings: Defining life cycle

zero energy buildings, Energy Build. (2010).

[33] A.J. Marszal, Zero Energy Building–A review of definitions and calculation methodologies, Energy Build. (2011).

[34] L. Aelenei, H. Gonçalves, From solar building design to net zero energy buildings: Performance insights of an office building, Energy Procedia. (2014).

[35] M. Heinze, K. Voss., Goal: Zero Energy Building exemplary experience based on the solar estate solarsiedlung freiburg am schlierberg, Germany, J. Green Build. (2009).

[36] E. Musall, Net Zero energy solar buildings: an overview and analysis on worldwide building projects, in: EuroSun Conf., 2010.

[37] The International Energy Agency (IEA) Net Zero Energy Buildings Database. http://iea40.buildinggreen.com/index.cfm (accessed December 16, 2015).

[38] D. Crawley, S. Pless, P. Torcellini, Getting to net zero. National Renewable Energy Laboratory, 2009., ASHRAE Journal, 2009.

[39] Concerted Action ,Energy Performance of Buildings Directive, (2014). http://www.epbd-ca.eu/ (accessed December 16, 2015).

[40] Directive 2010/31/EU of the european parlement and of the council of 19 May 2010 on the energy peformance of buildings, 2010.

[41] U.S. Department of Energy, Guidelines for Participating in the DOE Zero Energy Ready Home | Department of Energy, (2015). http://energy.gov/eere/buildings/guidelines-participating-doe-zero-energy-ready-home (accessed May 16, 2016).

[42] R. Fay, G. Treloar, U. Iyer-Raniga, Life-cycle energy analysis of buildings: a case study, Build. Res. Inf. 28 (2000) 31–41. doi:10.1080/096132100369073.

[43] B. Golestani, Sustainable Material Solution for Flexible Pavements: Performance Evaluation and Impact Assessment of Utilizing Multiple Recycled Materials in HMA, University of Central Florida, 2015.

[44] B. Golestani, H. Maherinia, B.H. Nam, A. Behzadan, Investigation on the Effects of Recycled Asphalt Shingle as an Additive to Hot-Mix Asphalt, Airf. Highw. Pavements 2015. (2015) 9–18.

[45] A. Sarkar, J. Singh, Financing energy efficiency in developing countries-lessons learned and remaining challenges, Energy Policy. 38 (2010) 5560–5571. doi:10.1016/j.enpol.2010.05.001.

[46] E. Ostrom, Nested externalities and polycentric institutions: must we wait for global solutions to climate change before taking actions at other scales?, Econ. Theory. 49 (2012) 353–369. doi:10.1007/s00199-010-0558-6.

[47] DOE, About the Building Technologies Office, Department of Energy. http://energy.gov/eere/buildings/about-building-technologies-office (accessed November 18, 2015).

[48] B. Golestani, B.H. Nam, F.M. Nejad, S. Fallah, Nanoclay application to asphalt concrete: Characterization of polymer and linear nanocomposite-modified asphalt binder and mixture, Constr. Build. Mater. 91 (2015) 32–38.

[49] M. Alirezaei, M. Noori, O. Tatari, K.R. Mackie, A. Elgamal, BIM-based Damage Estimation of Buildings under Earthquake Loading Condition, Procedia Eng. 145 (2016) 1051–1058.

[50] C. Balaras, et al, European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings, Build. Environ. (2007).

[51] C.A. Balaras, K. Droutsa, E. Dascalaki, S. Kontoyiannidis, Heating energy consumption and resulting environmental impact of European apartment buildings 37.5 (2005): 429-442., Energy Build. (2005).

[52] C. Ratti, N. Baker, K. Steemers., Energy consumption and urban texture." 37.7 (2005): 762-776., Energy Build. (2005).

[53] S.B. Sadineni, S. Madala, R.F. Boehm., Passive building energy savings: A review of

building envelope components, Renew. Sustain. Energy Rev. (2011).

[54] C.A. Balaras, et al, Potential for energy conservation in apartment buildings, Energy Build. (2000).

[55] G. Vishal, N.K. Bansal, Smart occupancy sensors to reduce energy consumption, Energy Build. (2000).

[56] J. Lu, et al, The smart thermostat: using occupancy sensors to save energy in homes, in: Proc. 8th ACM Conf. Embed. Networked Sens. Syst., 2010.

[57] T.A. Nguyen, M. Aiello, Energy intelligent buildings based on user activity: A survey, Energy Build. (2013).

[58] R. Rahmatizadeh, S.A. Khan, A.P. Jayasumana, D. Turgut, L. Bölöni, Routing towards a mobile sink using virtual coordinates in a wireless sensor network, in: 2014 IEEE Int. Conf. Commun., IEEE, 2014: pp. 12–17.

[59] R. Rahmatizadeh, S.A. Khan, A.P. Jayasumana, D. Turgut, L. Boloni, Circular Update Directional Virtual Coordinate Routing Protocol in Sensor Networks, in: 2015 IEEE Glob. Commun. Conf., IEEE, 2015: pp. 1–6.

[60] Fong, F. Kwong, H. Victor Ian, C. Tin-Tai, HVAC system optimization for energy management by evolutionary programming, Energy Build. (2006).

[61] E.H. Mathews, C.P. Botha, D.C. Arndt, A. Malan, HVAC control strategies to enhance comfort and minimise energy usage, Energy Build. 33 (2001) 853–863. doi:10.1016/S0378-7788(01)00075-5.

[62] K.F. Fong, V.I. Hanby, T.-T. Chow., “System optimization for HVAC energy management using the robust evolutionary algorithm.” 29.11 (2009): 2327-2334., Appl. Therm. Eng. (2009).

[63] N. Djuric, et al, Optimization of energy consumption in buildings with hydronic heating systems considering thermal comfort by use of computer-based tools, Energy Build. (2007).

[64] Wang, Weimin, R. Zmeureanu, R. Hugues, Applying multi-objective genetic algorithms in green building design optimization, Build. Environ. (2005).

[65] R. Banos, Optimization methods applied to renewable and sustainable energy: A review, Renew. Sustain. Energy Rev. (2011).

[66] M. Fesanghary, S. Asadi, Z.W. Geem, Design of low-emission and energy-efficient residential buildings using a multi-objective optimization algorithm, Build. Environ. (2012).

[67] M. Hamdy, A. Hasan, K. Siren, Applying a multi-objective optimization approach for design of low-emission cost-effective dwellings, Build. Environ. (2011).

[68] F. Oldewurtel, E. Al, Use of model predictive control and weather forecasts for energy efficient building climate control, Energy Build. (2012).

[69] DesignBuilder, DesignBuilder Optimisation, Des. Softw. Ltd. (2016). http://www.designbuilder.co.uk/content/view/158/226/ (accessed February 16, 2016).

[70] U.S. Energy Information Administration (EIA), Today in Energy, (2016). http://www.eia.gov/todayinenergy/detail.cfm?id=26712.

[71] U.S. Energy Information Administration (EIA), Renewable energy production and consumption by source, (2016). http://www.eia.gov/beta/MER/index.cfm?tbl=T10.01#/?f=A&start=1949&end=2015&charted=6-7-8-9-14.

[72] Solar - Energy Explained, Your Guide To Understanding Energy - Energy Information Administration.

[73] V. Fthenakis, J.E. Mason, K. Zweibel, The technical, geographical, and economic feasibility for solar energy to supply the energy needs of the US, Energy Policy. (2009).

[74] How a PV System Works, Florida Sol. Energy Cent. (2014).

[75] R. Charron, A. Athienitis, Design and optimization of net zero energy solar homes, Trans.

Soc. Heat. Refrig. AIR Cond. Eng. (2006).

[76] M.T." Iqbal, A feasibility study of a zero energy home in Newfoundland, Renew. Energy. (2004).

[77] M.R. Elkinton, J.G. McGowan, J.F. Manwell, Wind power systems for zero net energy housing in the United States, Renew. Energy. (2009).

[78] M. Noori, M. Kucukvar, O. Tatari, A macro-level decision analysis of wind power as a solution for sustainable energy in the USA, Int. J. Sustain. Energy. 34 (2015) 629–644. doi:10.1080/14786451.2013.854796.

[79] J. Li, L. Ma, S. Wang, W. Yu, F. Lv, J. Yang, et al., Background Paper: Chinese renewables status report-October 2009, (2009).

[80] M. Hooshyar, S. Kim, D. Wang, S.C. Medeiros, Wet channel network extraction by integrating LiDAR intensity and elevation data, Water Resour. Res. 51 (2015) 10029–10046.

[81] J.P. Praene, M. David, F. Sinama, D. Morau, O. Marc, Renewable energy: Progressing towards a net zero energy island, the case of Reunion Island, Renew. Sustain. Energy Rev. 16 (2012) 426–442. doi:10.1016/j.rser.2011.08.007.

[82] R. Chase, Does Everyone in America Own a Car?, 2010.

[83] R. Chase, Does Everyone in America Own a Car?, 2011.

[84] M. de BONCOURT, The Electric Vehicle in the Climate Change Race, 2011. http://www.ifri.org/?page=detail-contribution&id=6543&id_provenance=97.

[85] R.F. Nelson, Power requirements for batteries in hybrid electric vehicles, J. Power Sources. 91 (2000) 2–26. doi:10.1016/S0378-7753(00)00483-3.

[86] M. Moynihan, Unlocking the Power of the Open Energy Network (OEN), 2010.

[87] M. Alirezaei, M. Mofid, H. Tajamolian, An investigation into the seismic behavior of single-story concrete frames equipped with metallic yielding dampers, Sci. Iran. Trans. A, Civ. Eng. 22 (2015) 2061.

[88] M. Lott, Bridging the Gap Between Supply and Demand, J. Int. Energy Agency. (2014).

[89] H. Lee, G. Lovellette, Will Electric Cars Transform The U.S. Vehicle Market?, Energy Technol. Innov. Policy Int. Aff. (2011).

[90] H. Lee, G. Lovellette, Will electric cars transform the US market?, Energy Technology Innovation Policy Research Group, 2011.

[91] M. Noori, O. Tatari, Development of an agent-based model for regional market penetration projections of electric vehicles in the United States, Energy. 96 (2016) 215–230.

[92] G. Haines, A. McGordon, P. Jennings, The simulation of vehicle-to-home systems–using electric vehicle battery storage to smooth domestic electricity demand, in: EVER Monaco, 2009.

[93] H. Hvidtfeldt, L. Sonderberg, Energy Storage Options for Future Sustainable Energy Systems, 2013.

[94] W. Kempton, J. Tomić, Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy, J. Power Sources. 144 (2005) 280–294. doi:10.1016/j.jpowsour.2004.12.022.

[95] “Vehicle to Home” Electricity Supply System ,NISSAN ,Technological development activities, (2014). http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/vehicle_to_home.html (accessed November 23, 2015).

[96] W. Kempton, J. Tomić, Vehicle-to-grid power fundamentals: Calculating capacity and net revenue, J. Power Sources. 144 (2005) 268–279. doi:10.1016/j.jpowsour.2004.12.025.

[97] J. Tomić, W. Kempton, Using fleets of electric-drive vehicles for grid support, J. Power Sources. 168 (2007) 459–468.

[98] W. Kempton, J. Tomić, Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy, J. Power Sources. 144 (2005) 280–294.

[99] C. Guille, G. Gross, A conceptual framework for the vehicle-to-grid (V2G) implementation, Energy Policy. 37 (2009) 4379–4390.

[100] B.K. Sovacool, R.F. Hirsh, Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition, Energy Policy. 37 (2009) 1095–1103.

[101] M. Noori, Y. Zhao, N.C. Onat, S. Gardner, O. Tatari, Light-duty electric vehicles to improve the integrity of the electricity grid through Vehicle-to-Grid technology: Analysis of regional net revenue and emissions savings, Appl. Energy. 168 (2016) 146–158.

[102] T. Ercan, M. Noori, Y. Zhao, O. Tatari, On the Front Lines of a Sustainable Transportation Fleet: Applications of Vehicle-to-Grid Technology for Transit and School Buses, Energies. 9 (2016) 230.

[103] C. Liu, S. Gao, . "Opportunities and challenges of vehicle-to-home, vehicle-to-vehicle, and vehicle-to-grid technologies, in: IEEE 101.11, 2013.

[104] I. Cvetkovic, Future home uninterruptible renewable energy system with vehicle-to-grid technology." , 2009. ECCE 2009. IEEE. IEEE, 2009., in: Energy Convers. Congr. Expo., 2009.

[105] M. Noori, et al, “Light-duty electric vehicles to improve the integrity of the electricity grid through Vehicle-to-Grid technology: Analysis of regional net revenue and emissions savings.,” Appl. Energy. (2016).

[106] M. Noori, S. Gardner, O. Tatari, Electric vehicle cost, emissions, and water footprint in the United States: Development of a regional optimization model, Energy. (2015).

[107] M. Noori, Developement of Regional Optimization and Market Penetration Models for Electric Vehicles in the United States, 2015.

[108] U.S. Department of Energy, Smart Charging and V2X, Dep. Energy. (2014). http://www.energy.ca.gov/research/epic/documents/2014-06-

30_workshop/presentations/Nissan_North_America-Smart_Charging_and_V2X.pdf (accessed April 4, 2016).

[109] M. Noori, Development of Regional Optimization and Market Penetration Models For Electric Vehicles in the United States, (2015).

[110] R. Axtell, Why agents?: on the varied motivations for agent computing in the social sciences, (2000).

[111] M. Alirezaei, M. Noori, O. Tatari, Getting to net zero energy building: investigating the role of vehicle to home technology, Energy Build. (2016).

[112] T. Ueno, F. Sano, O. Saeki, K. Tsuji, Effectiveness of an energy-consumption information system on energy savings in residential houses based on monitored data, Appl. Energy. 83 (2006) 166–183.

[113] Schneider Electric, Monitoring Energy Use : The Power of Information, 2011.

[114] National Renewable Energy Laboratory (NREL), Third-Party Graphical User Interfaces, (2015).

[115] Department of Energy, Building Technologies Office: EnergyPlus Energy Simulation Software, Dep. Energy. http://apps1.eere.energy.gov/buildings/energyplus/ (accessed November 13, 2015).

[116] DesignBuilder, Simulation Hourly Weather Data, (2015).

[117] Energy3D: Learning to Build a Sustainable Future, (2015). http://energy.concord.org/energy3d/ (accessed December 4, 2015).

[118] DesignBuilder Software Product Overview. http://www.designbuilder.co.uk/content/view/144/223/ (accessed November 13, 2015).

[119] W. Wang, R. Zmeureanu, H. Rivard, Applying multi-objective genetic algorithms in green building design optimization, Build. Environ. 40 (2005) 1512–1525. doi:10.1016/j.buildenv.2004.11.017.

[120] R. a Urban, B.R. Bakshi, Techno-ecological synergy as a path toward sustainability of a North American residential system., Environ. Sci. Technol. 47 (2013) 1985–93. doi:10.1021/es303025c.

[121] D. Whitley, A Genetic Algorithm Tutorial by Darrell Whitley, Statisitcs Comput. (1994). http://samizdat.mines.edu/ga_tutorial/.

[122] ASHRAE Technical FAQ, What are the recommended indoor temperature and humidity levels for homes?, (2013) 2009–2010.

[123] U.S Department of Energy, Thermostats and indoor temperature, 2016. http://energy.gov/energysaver/thermostats.

[124] DOE, Progress Report: Advancing Solar Energy Across America | Department of Energy, Dep. Energy. (2014). http://energy.gov/articles/progress-report-advancing-solar-energy-across-america (accessed February 12, 2016).

[125] T.H. Bradley, A.A. Frank, Design , demonstrations and sustainability impact assessments for plug-in hybrid electric vehicles, Renew. Sustain. Energy Rev. 13 (2009) 115–128. doi:10.1016/j.rser.2007.05.003.

[126] NISSAN | Nissan and Nichicon to Launch the “LEAF to Home” Power Supply System With “EV Power Station,”. http://www.nissan-global.com/EN/NEWS/2012/_STORY/120530-01-e.html (accessed December 1, 2015).

[127] USDOE, Electric Vehicles, Dep. Energy. (2015). https://www.fueleconomy.gov/feg/evtech.shtml (accessed February 7, 2016).

[128] OUC, Solar, Orlando Util. Comm. (2016). http://www.ouc.com/environment-community/solar (accessed February 17, 2016).

[129] OUC, Electric Rates, Orlando Util. Comm. (2016). http://www.ouc.com/residential/service-rates-and-costs/electric-rates (accessed February 18, 2016).

[130] H. Doukas, K.D. Patlitzianas, K. Iatropoulos, J. Psarras, Intelligent building energy

management system using rule sets, Build. Environ. 42 (2007) 3562–3569.

[131] DOE, Tips: Time-Based Electricity Rates, (2016). http://energy.gov/energysaver/tips-time-based-electricity-rates (accessed January 29, 2016).

[132] Smartgrid, Time Based Rate Programs, (2016). https://www.smartgrid.gov/recovery_act/time_based_rate_programs.html (accessed January 29, 2016).

[133] U.S. Department of Energy, U.S. Energy Use Intensity by Property Type, (2016). https://portfoliomanager.energystar.gov/pdf/reference/US National Median Table.pdf (accessed May 16, 2016).

[134] TESLA, Tesla Powerwall, (2015). https://www.teslamotors.com/powerwall (accessed April 7, 2016).

[135] T.H. Bradley, A.A. Frank, Design, demonstrations and sustainability impact assessments for plug-in hybrid electric vehicles, Renew. Sustain. Energy Rev. 13 (2009) 115–128.

[136] U.S. Energy Information Administration, What is U.S. electricity generation by energy source?, EIA. (2016). https://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3 (accessed April 13, 2016).

[137] U.S.E.I. Administration, How is electricity used in U.S. homes? - FAQ - U.S. Energy Information Administration (EIA), EIA. (2015). https://www.eia.gov/tools/faqs/faq.cfm?id=96&t=3 (accessed April 13, 2016).

[138] Designbuilder, Simulation Detailed Results, (2015). http://www.designbuilder.co.uk/helpv2/Content/Simulation_Detailed_Results.htm (accessed February 4, 2016).

[139] Energy Information Administration (EIA), How much energy is consumed in residential and commercial buildings in the United States? - FAQ - U.S., (2016). http://www.eia.gov/tools/faqs/faq.cfm?id=86&t=1 (accessed April 29, 2016).

[140] U.S. Department of Energy, Buildings Energy Data Book, (2012). http://buildingsdatabook.eren.doe.gov/ChapterIntro1.aspx (accessed April 29, 2016).

[141] EERE, Energy Efficiency Trends in Residential and Commercial Buildings, (2008).

[142] C.C.D. US EPA, Electricity Sector Emissions, (2016). https://www3.epa.gov/climatechange/ghgemissions/sources/electricity.html (accessed April 29, 2016).

[143] U.S. Energy Information Administration, How much coal, natural gas, or petroleum is used to generate a kilowatthour of electricity?, (2016). https://www.eia.gov/tools/faqs/faq.cfm?id=667&t=3 (accessed April 29, 2016).

[144] United States Environmental Protection Agency, GHG Equivalencies Calculator - Calculations and References, (2015). https://www.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references (accessed May 2, 2016).

[145] U.S. Energy Information Administration, Carbon Dioxide Emissions Coefficients, (2016). https://www.eia.gov/environment/emissions/co2_vol_mass.cfm (accessed May 2, 2016).

[146] U.S. Energy Information Administration, Average tested heat rates by prime mover and energy source, (2014). https://www.eia.gov/electricity/annual/html/epa_08_02.html (accessed May 2, 2016).

[147] P. Menanteau, D. Finon, M.-L. Lamy, Prices versus quantities: choosing policies for promoting the development of renewable energy, Energy Policy. 31 (2003) 799–812.

[148] R.G. Sargent, Verification and validation of simulation models, in: Proc. 37th Conf. Winter Simul., winter simulation conference, 2005: pp. 130–143.

[149] S. Robinson, Simulation model verification and validation: increasing the users' confidence, in: Proc. 29th Conf. Winter Simul., IEEE Computer Society, 1997: pp. 53–59.

[150] L.L. Pullum, X. Cui, Techniques and issues in agent-based modeling validation, Technical report, Oak Ridge National Laboratory, 2012.

[151] E.J. Weyuker, On testing non-testable programs, Comput. J. 25 (1982) 465–470.

[152] Texas A&M Transportation Institute, Annual Urban Mobility Scorecard , Urban Mobility Information, (2015). https://mobility.tamu.edu/ums/.

[153] W.M. Strohbach, E. Arnold, D. Hasse, The carbon footprint of urban green space-A life cycle approach, Landsc. Urban Plan. (2012).

[154] D. Nowak, D. Crane, Carbon storage and sequestration by urban trees in the USA, Environ. Pollut. (2002).