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Optimal design of HVAC systems for the design of nearly Zero Energy Buildings under different climate conditions

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Abstract

This master thesis aims to develop a methodology to identify the optimal operation of different HVAC system configurations for different climate conditions and building typologies. To reach the objective, the work is carried out in three main steps using dedicated tools (DesignBuilder, EnergyPlus, and eppy script (python language)) and running co-simulation. In addition, the nZEB standard established by the most recent edition of the Spanish Technical Building Code is addressed in this study through a parametric optimization study of a reference building. The effectiveness of this legislation is evaluated in terms of its capacity to disseminate the idea of building energy cost optimization and reduce the annual energy consumption in the residential sector. To this end, a reference building was designed and multiple HVAC designs were evaluated using DesignBuilder building energy simulation software and found the best optimization of HVAC solutions through EnergyPlus and eppy. In total, a set of 30 alternative scenarios was established and parametrically evaluated for 5 cities representing the 5 climatic zones of inland Spain (Bilbao, Burgos, Seville, Madrid, and Almeria) resulting in 150 simulations. The results were evaluated utilizing annual energy consumption (electricity, natural gas, and other fuels) values concerning the calibration of set point manager temperature (heating), obtaining the cost-optimal and minimum consumption levels of annual energy. It is worth mentioning that this study is mainly concentrating on the Energy Supply System (ESS), where the Energy Saving Measure (ESM) is kept unchanged, which should be reviewed in future updates.

Keywords: nZEB, HVAC, building energy optimization, parametric optimization, EnergyPlus, eppy

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Introduction

The building sector is presently one of the largest consumer energy sectors in the world. The building industry was responsible for 36% of the world's total final energy consumption as well as 37% of CO_2 emissions connected to energy use. Even though there was a decrease in emissions, which was mostly caused by the COVID-19 situation. However, there is still concern that construction demand may cause emissions to increase. Researchers and engineers have been pushed to concentrate on the problem of energy usage in buildings because of rising living standards and diminishing sources of fossil fuels. HVAC (Heating, Ventilation, and Air Conditioning) systems are among the highest users of energy in buildings; this is even though HVAC serve a crucial role in ensuring that occupants are comfortable. An interesting possibility exists for large savings in energy use if performance upgrades are made to conventional HVAC systems. In commercial buildings, about half of the energy used is devoted to maintaining a comfortable temperature. A major factor in lowering global energy consumption will be the development of HVAC systems that do not use fossil fuels and are thus more energy efficient.

Residential, commercial, and industrial buildings' increasing dependence on HVAC systems has led to an explosion in energy use, especially during the hotter months. Both customers and the environment benefit from developing energy-efficient HVAC systems, which are necessary to counteract rising power prices and the negative effects of greenhouse gas emissions generated by the usage of inefficient electrical equipment. As a result of significant advances in science and technology, there are a variety of ways to develop energy-efficient HVAC systems. The goal of designing HVAC system is to provide a specific degree of thermal comfort in buildings, however, this often entails a high energy consumption and expensive installation costs. In buildings, the primary purpose for which energy is ultimately used for heating and cooling, regardless of the season.

The energy consumption of buildings is closely related to the energy efficiency of the HVAC systems. However, this study aims to develop a methodology to identify the optimal operation of different HVAC system configurations for different climate conditions and building typologies. This study assessed the energy efficiency, comfort levels, and economic viability of commercially available HVAC solutions for a residential nZEB (nearly Zero Energy Building). The proposed methodology will be based on the optimization of HVAC solutions through massive building energy simulations using the DesignBuilder (DB) building energy simulation software and eppy scripting tool for EnergyPlus (E+). The results will be a mapping of best HVAC practices for different countries and the effect of different constraints, as well as the effect of the influence of certain cost and performance parameters.

Thus, this book is separated into 6 chapters. The first chapter discussed the previous research gap, findings, and improvements that are related to this study. The second chapter provides the context and objectives of this work more specifically. The third chapter is mainly focused on the methods of this study which is divided into three parts to achieving the aim of this master thesis. Chapter four focuses mainly on the case study (building design, HVAC design) details that are used for this study. The findings of the study are discussed in details in Chapter 5, which also displays the findings. Finally, the last chapter of this book is focused on a discussion of upcoming work as well as a summary of the work.

1 Literature Review

The main objective of this chapter is to find the relevant literature and potential gaps related to the “nZEB HVAC system”. Actually, this chapter is divided into four parts: a) introduction to HVAC and nZEB, b) literature on the HVAC system in the simulation tool, c) literature conducted with real measurements of the HVAC system, and d) literature conducted on the HVAC control system. Finally, the chapter ends with a possible solution to the research gaps and a conclusion.

The idea of "nearly Zero Energy Buildings" also known as "nZEBs" is explored on a worldwide scale via the implementation of both active and passive measures [1]. Minimizing the energy demand and consumption of the building and expanding on-site renewable energy production are the primary means by which advances in nZEBs are made. 40% of energy consumption and 36% of GHG emissions in the European Union (EU) are attributable to buildings, as a result of their construction, use, repair, and decommissioning [2]. In addition, the residential building sector accounts for 45% of energy consumption for heating and cooling in the EU, the industrial sector is responsible for 37% of the economy, while the service sector is accountable for 18% [3, 4]. Investigating the energy usage of HVAC equipment on a global scale reveals the following notable figures: for instance, in the United States, HVAC systems contribute to almost half of a building's total energy consumption [5, 6]. Over the last two decades, China's building energy usage has increased at a pace of nearly 10% per year and currently accounts for approximately 20.7% of the country's overall energy consumption [7]. Around 40% of Europe's energy usage is accounted for by business and residential construction [8]. Non-residential buildings in Australia use 70% of their energy from HVAC systems [9]. In India, a building's air conditioning system accounts for around 32% of its total energy consumption [10]. In 2006, air conditioning and refrigeration systems accounted for 33% of Hong Kong's energy consumption [11]. More than 70% of the energy used in buildings in the Middle East is consumed by cooling systems [12]. Between 2001 and 2005, the world's energy consumption was expected to have climbed by 58% [13]. About 80% of total energy consumption is derived from fossil fuels [14-16].

1.1 HVAC system in the simulation tool

In this subsection, relevant research on the HVAC system conducted in the simulation tool is reviewed to understand the gap in the related research works more precisely. Actually, Ventilation through windows, doors, walls, ventilators, etc., is a vital aspect of the HVAC system. A study demonstrates that using a proper glazing system and heat gain coefficient reduced energy bills by up to 47% annually. Energy plus software was used to calculate the thermal values considering the building's HVAC system consists of a natural gas boiler and electric coils [17]. However, this study didn't provide a clear idea about the cooling and heating procedure. Additionally, few researchers from Italy did research related to the "Benevento" Nearly Zero Energy Building (BNZEB) which is more connected with the Mediterranean climate. They evaluated the building's energy performance throughout the summer season. Particularly, a numerical model was analyzed in the case study building, which was in charge of performing transient energy simulations in order to compare the BNZEB building to other buildings. However, this research was not limited to the Italian climate; later, the researcher performed their analysis of other Mediterranean cities, such as Montpellier, Athens, Seville, Madrid, and Lisbon [18].

Another review article was prepared by W. Wu and H.M. Skye in the buildings sector, more specifically, the last ten years of residential nZEBs [19]. The connectivity to energy facilities that have been considered includes electrical grids, district heating and cooling networks, and various possibilities for energy storage, such as vehicle-to-home and hydrogen storage. The last category discussed is energy-efficiency techniques, which include enhanced building envelope structures, effective HVAC systems, effective domestic hot water systems, and the incorporation of phase change materials. There are several various technology alternatives available within each of these categories; this not only makes it more difficult to pick the "optimal" configuration but also enables more design flexibility to accommodate varying regional climates and other factors (i.e., building codes, energy resources, costs) [19].

S.M. M. Ahmed et al. did research on nZEB using DesignBuilder software. This office building design was for 20 structures in an official zone [20]. After that, a plan was selected for the micro-grid that would be constructed in this official zone to satisfy the nZEB criteria of the European Union and lower the energy demand via the main grid. In addition, each office building should have a Solar PV power plant installed on its rooftop to meet its energy requirements. This research intends to establish an official nZEB zone by combining Solar PV and Wind Turbine generating systems with a microgrid, therefore enhancing renewable energy production and contributing to the growth of the economy [20].

J.M. Santos-Herrero and his team reviewed articles on the nZEB concept [21]. Moreover, a research gap had also been identified, and as a result, allowing concepts, such as Building Energy Performance Simulation (BEPS) tools and Model Predictive Control (MPC), have been assessed. As a result, it is feasible to control an HVAC system in an efficient manner utilizing RES, so lowering CO_2 emissions concerns globally and achieving significant energy savings [21].

Researchers from India did research on nZEB; in developing nZEB, the technical factors of planning, orientation, envelope, HVAC, use of energy-efficient materials, and integration of renewable energy system were examined and assessed [22]. On a computer-generated model of the building, analysis, assessment, and validation were performed. In order to meet the building's reduced yearly energy needs, a rooftop solar photovoltaic power plant with a capacity of 300 kWp was used to generate renewable energy and achieve a net-zero energy balance [22].

K. S. Cetin et al. developed and validated the HVAC system in EnergyPlus, that a customized EMS is being used to construct an on/off controller for the domestic sector (energy management system) [23]. This controller is tested utilizing minute-level data collected from a building in Sacramento, California, with simulated occupancy and domestic loads. The EnergyPlus outcomes are also assessed with and without the on/off option of the controller. In respect of the on/off function of the home direct expansion coils, it also enables the HVAC system's mode of operation and accompanying energy consumption signal to be more genuine. In addition, the accuracy of the findings influenced by internal factors is explored in this research by using each schedule instead of the regular hourly schedules for the inner thermal loads [23].

P. W. Tien et al. did research on identifying and recognizing manual window operations in buildings using deep learning strategies [24]. A developed deep learning model is implemented in a camera influenced by artificial intelligence. To evaluate the effectiveness of the suggested technique, a building energy simulation was conducted with varied operating profiles of window openings depending on several circumstances. Initial trial experiments were performed in a lecture hall with a south-facing window. The findings of the three cases indicated that the suggested technique might be utilized to assist in adjusting the HVAC setpoint or notifying occupants or building management to avoid needless heating demand. The framework's capacity to recognize numerous window opening kinds and sizes, as well as the model's detection precision, will be improved in further improvements [24].

Besides, S. M. Safavisohi conducted research that developed and evaluated many solutions for an HVAC system's summer and winter design of a public building in Turin [25]. Such a system comprises variable air volume (VAV), a fan coil system with chiller and boiler, and variable refrigerant flow (VRF). This research indicates that the VRF system is superior to the other two HVAC systems since it is dependable, distributes refrigerant rather than hot and cold water through pipes to terminal units, and distributes varying amounts of refrigerant simultaneously delivers heating and cooling. Moreover, because their initial cost is expensive, they are about 30% more efficient than alternative systems [25].

Moreover, S. Daz de Garayo devoted one year to doing research on the energy performance of a residential building [26]. As a result, the thermoelectric HVAC system retains the inside temperature between 20–23 °C in the winter and 23–25 °C in the summer by precisely controlling the voltage provided to the thermoelectric heat pump, which can vary the heating/cooling capacity from 5% to 100%. Compared to the thermoelectric system, which permits only 270 Wp to be saved, the vapor compression system decreases electric energy usage by 36.1%. This shows how thermoelectricity may be used to heat and cool passive dwellings [26].

Also, O.F. Yildiz et al. examined and assessed the impact of different energy conservation measures on energy consumption and CO_2 emissions, along with various adjustments that may be made to airport terminal building HVAC systems [27]. Erzurum Airport Terminal Building was selected as the airport terminal building since it is situated in Turkey's coldest temperature zone. This suggests that the suggested energy-saving measures may cut energy consumption and CO_2 emissions by 57.24% and 48.79%, respectively [27].

This article presents the implementation approach for an occupancy-based HVAC system operating schedule developed by A. Capozzoli et al. [28]. The method is based on the practicality of relocating groups of tenants with comparable occupation patterns to the same thermal zone. Using an average week's occupancy patterns, optimization of the scheduling of an HVAC system was examined. The approach was used in the analysis of the Zaanstad Town Hall in the Netherlands, which included anonymous occupancy data for four months. The optimized plan was then tested using an energy simulation technique using a model calibrated with real-world energy usage data. In comparison to an occupancy-independent operating plan, the technique resulted in a 14% reduction in energy consumption of the HVAC system. The suggested method may be generalized to assist energy managers in determining the best occupancy-based HVAC system operating schedules [28].

In addition, A. A. Alotaibi investigated PCM used buildings to minimize energy usage in HVAC systems [29]. In Saudi Arabia, five climatic areas with a yearly average temperature of 2–28.5 °C were investigated. Because of the great intensity of the irradiation, such regions are classified as warm and dry (global intensity radiation of higher than 2100 kWh/m^2.year). The envelopes were fitted with six PCMs with a melting temperature range of 21–32 °C, and it was discovered that these materials reduced HVAC PD in each site. Due to the cold temperatures in the third region, PCMs were ineffective in the winter. The HVAC PD was significantly weakened by all six substances in the summer. Finally, the greatest result was awarded to A27 and A29 PCMs based on a yearly study. PCM A29 decreased HVAC PD throughout all areas except the second by 101.5 kWh/m^2, 84 kWh/m^2, 104 kWh/m^2, and 93 kWh/m^2 for various locations. The best solution for site 2 was A29, which reduced HVAC PD by 102.6 kWh/m^2 [29].

The influence of phase change material (PCM) in 10 climate regions with an average temperature of 13.1–26.9 °C was studied by R. Kalbasi et al., emphasizing comfort time [30]. The development of energy equations for the entire building, as well as momentum and continuous formulas for PCM, yielded numerical findings. Five materials with melting temperatures ranging from 18 to 24 °C were chosen to find an appropriate PCM, and it was discovered that the comfortable temperature range had little influence on the PCM. It was found that for a basic structure (without PCM), the comfort time percent changed between 26% and 40% by setting the comfort range to 18–27 °C. The comfort time percent increased by 54–82% when PCM was added. In other respects, if an appropriate PCM is present, the interior temperature may be regulated between 18 and 27 °C for up to 82% of the year. PCM-22 was a good fit for six locations in our situation (out of ten regions). PCM-23 was shown to be appropriate for eight areas in settings ranging from

20 to 25 °C. The temperature was adjusted in the range of 20–25 °C if PCM-23 was added to traditional buildings that did not use energy for at least 54% of the year [30].

Also, the HVAC energy prediction model was investigated by H. Sha et al. Building energy prediction was traditionally done using two categories of driven models: sequential and parallel predictive models [31]. The latter uses previous energy data from the target building as test examples to estimate future energy consumption. Since the model input characteristic was challenging to detect and gather, the second prediction model is rarely researched. A unique key-variable-based parallel HVAC energy prediction model was provided in this paper. This model has a basic design and user input features. A generic key-variable screening toolkit that was more adaptable and adjustable than existing parametric analytic tools was created to identify critical variables for the parallel HVAC energy forecasting model. A case study is carried out to screen the essential factors of hotel buildings in eastern China, and a parallel chiller energy forecasting model is developed and evaluated on the basis of the results [31].

Six different Heating systems (water-cooled and air-cooled variable flow cooling systems, air handling unit systems, fan coil systems, water source and air source heat pump systems, and split air conditioning system) were also evaluated in terms of power consumption, initial capital costs, operating costs, and easy operation by K. YASIN et al. during an investigation on HVAC System of an office [32]. The benefits and drawbacks of the systems were evaluated, and the calculations revealed that air-cooled systems use 33% less energy than water-cooled systems and have 30% lower capital costs [32].

A. Akgüç and colleagues performed research to enhance the energy performance of high-rise residential buildings using the cost-optimal framework technique outlined in the Recast Directive on Energy Performance of Buildings (EPBD 2010/31/EU) [33]. Turkey is obligated to comply with the terms of this Directive since it is identified as an EU applicant and is in the process of gaining full membership. Modern retrofit approaches to increase the energy efficiency of HVAC systems were recommended in the current research, which is based on a high-rise residential building in Turkey that serves as a sample case study. According to the findings, using decentralized heat recovery ventilator systems in conjunction with a demand-controlled ventilation approach in high-rise residential buildings might reduce energy usage by 39% annually. Furthermore, the employment of solar and waste heat recovery systems was shown to be much better in enhancing the energy efficiency of multistorey residential buildings in cost-optimal situations. The abovementioned retrofit methods helped reduce yearly energy usage and worldwide cost by 50% and 23%, respectively, in the current research. As a result, it was proposed that solar and waste heat recovery systems in high-rise residential buildings were obligatory via increased incentives for renewable energy systems and changes to Turkey's construction rules [33].

Therefore, Researchers from Croatia conducted research regarding the HVAC system in the nZEB aspect [34]. Moreover, the dynamic simulation models built in the Trnsys program as the optimization engine to reduce global cost (GC) and primary energy consumption (PEC). Various HVAC systems, varying from traditional natural gas-based methods to systems powered by renewable energy sources, were explored (RES). The strategy is used in the case study of the renovation of a prominent hotel on the Croatian Adriatic. In addition to an HVAC system with a low PEC, the use of a solar photovoltaic (PV) system is necessary to meet the nZEB objective for a renovated hotel in Croatia (115 kWh/m^2), according to the results of this study [34].

1.2 Real measurements of HVAC system

In this subsection, the relevant research on HVAC systems that have been undertaken using actual measurements is analyzed in order to identify the research gap more clearly. Human's way of living is improving day by day with the use of modern technology. Now, most people are aware of the impact of climate change and green energy. As a result, the main priority is now ecological balance considering a comfortable lifestyle. A suitable building design using proper weather resources can eliminate the rate of energy consumption. From this concept, the HVAC system was introduced. New buildings use local meteorological data and resources effectively, and smart forecasts and precise HVAC systems reduce energy use [35].

A huge amount of heat comes through the ceiling, which is also considerable for the heating and cooling system. The energy consumption of a building was reduced by enclosing it with three various categories of materials in diverse temperature zones. An experiment was conducted using ordinary insulating glass (OIG), heat reflective insulating glass (HFIG), and triple silver low-e insulating glass (TSIG), and it was discovered that TSIG provides consistent energy savings in both heating and cooling systems. However, the proposed method could not provide significant heating [36].

In addition, five years of meteorological data were analyzed to compare energy consumption to the first year of operation. Finally, net primary energy might drop from 25.4 kWh/m^2 year to 19.5 kWh/m^2 year in the worst-case weather scenario with an 85% self-consumption rate [37]. Moreover, W. Wu and H.M. Skye conducted research regarding comparing energy performance and cost of PV and HVAC equipment for nZEB in various climate zones in the US. Depending on the HVAC system and climatic zone, the HVAC contributed roughly 23.8 % to 72.9 % of the overall building energy consumption. In the colder northern climates of Chicago, Minneapolis, Helena, and Duluth, the HRV was found cost-effective, with energy savings ranging from 17.3% to 19.7% [38].

Consequently, R. Stasi et al. conducted research on nZEBs in the Mediterranean climate [39]. This research investigates the design requirements, thermodynamic behavior, and ultimate energy consumption of an nZEB. The case study focuses on a 309 m^2 single-family home in Mesagne, a small town in southern Italy. This investigation confirms how a passive building design coupled with an efficient plant system may effortlessly fulfill the nZEB standards with great efficiency in terms of energy consumption and thermal comfort [39].

M Dey et al. did research on detecting faulty HVAC system Terminal Unit (TU). In order to accomplish this goal, a framework characteristic of big data has been created so that a very high amount of data can be processed [40]. The findings of the clustering and categorization were then evaluated by statistical measures and particularly compared to well-known and recognized techniques [40].

Therefore, M. Biemann et al. perform assessments in a digital data center to assess four actor-critic systems [41]. The assessment of their effectiveness is predicated on their capacity to retain thermal stability and improve energy efficiency, as well as their flexibility to weather changes. Due to the immense importance of real-world applications, data efficiency is given significant consideration. All applicable algorithms will cut energy usage by at least 10% relative to the EnergyPlus (E+) model-based controller while maintaining the required hourly average temperature concurrently. Assessments of robustness validate these findings with respect to various incentive mechanisms and weather circumstances [41].

W. R. Chan et al. did research on HVAC systems. This research evaluated a total of 104 classrooms from 11 schools that had recently retrofitted HVAC system upgrades [42]. The CO_2 percentage, room temperature, supply air temperature, humidity levels, and door opening were recorded in each class over four weeks. In 51% of the rooms examined, field assessments revealed issues with HVAC systems, fan control, and filter maintenance. Economizer-equipped classrooms, whether with or without demand control ventilation (DCV), reported lower mean CO_2 levels. However, several of the classrooms in this study were much too warm to be conducive to learning. Therefore, better management of HVAC system installation is required to guarantee proper classroom ventilation. To identify and repair ventilation issues, it is advised that ventilation systems be inspected on a regular basis and continuous real-time CO_2 monitoring be carried out [42].

A. Vishwanath et al. examined the effectiveness of a data-driven energy cost optimization method for decreasing HVAC cooling energy usage of a corporate building via experiments [43]. First, they design an integer linear program (ILP)-based cooling optimization methodology with the objective of minimizing the energy expenses incurred for cooling a building while maintaining the thermal comfort of the inhabitants. Secondly, the framework's structure of the system was discussed, which was deployed on the IBM cloud service. Thirdly, researchers used the framework to manage the HVAC system of a large office complex in northern Australia. This data-driven approach was cost-effective, expandable, and leverages sensor data that all BMSs widely document to provide facility managers with an effective and practical means of reducing the energy usage of their building's HVAC system [43].

Several model-free reinforcement learning algorithms were used to interactively regulate HVAC and blind systems in a multi-zone test facility in situations with and without automated light dimming in relation to illumination levels by Tianyu Zhang et al. [44]. Researchers examined the three-way trade-off among energy usage, thermal comfort, and visual comfort and discussed how the combined management of building systems might give a better trade-off than when they have been regulated independently. Incorporating zone-specific occupancy data, Researchers demonstrated that 11% and 31.8% more energy could be saved throughout the heating and cooling seasons than the present rule-based baseline methods that manage identical building systems [44].

1.3 HVAC Control

In this subsection, the relevant research on HVAC system control is evaluated so that the research need will be identified more precisely. M. Borrelli et al. optimized the heating design of an nZEB educational building. The fundamental objective of this research was to figure out how the heating system's energy efficiency is affected by control techniques, as well as the essential part played by the control strategies [45]. Furthermore, an in-depth investigation was conducted by researchers to measure the real operation and the building's energy consumption. Afterward, a building energy simulation (BES) modeling of the building as well as its components was built and calibrated using actual measurements. The simulation findings demonstrate that methods based on the design of a heating curve for the boiler could reduce the comfort time (23%) [45].

S. Papadopoulos and his team conducted research on HVAC temperature setpoints in commercial buildings [46]. During this work, simulation-based multi-objective optimization was used to optimize the heating and cooling setpoints of large "typical" office buildings with consideration of both the amount of energy used and the level of thermal comfort experienced by the building's occupants. Researchers illustrate that yearly HVAC-related energy savings may be as high as 60% without affecting occupant thermal comfort in milder climates, such as San Francisco, CA. The discussion on reviewing HVAC setpoint configuration standards in office buildings, as either part of individual structure upgrade planning or as part of energy policy rules, is prompted by this untapped potential to increase building efficiency and occupant comfort at the same time [46].

W. Jung and F. Jazizadeh completed an investigation on thermal comfort and temperature variations [47]. Actually, an agent-based control mechanism was proposed to simulate a multi-occupancy environment controlled by an HVAC agent to provide air conditioning for numerous inhabitants using three distinct operational techniques to evaluate how well the suggested methodology compares to traditional ways. The first technique is based on the interests of most individuals, the second concept is based on the difference between people's preferences and the environment's temperature, and the third approach utilizes both choices and is sensitive to thermal comfort. Our research revealed that thermal comfort sensitivity performs a statistically significant role in collective conditioning, as it led to adjustments in temperature setpoint in 86% of instances and a greater likelihood of obtaining collective comfort [47].

B. F. Santoroa led research on an economic nonlinear model predictive control (eMPC). With this approach, facility managers will gain the ability to achieve a balance between operational costs and thermal comfort [48]. Afterward, the developed HVAC system was evaluated under open-loop and closed-loop circumstances. This method ensures a user-friendly interface among facility managers and eMPC [48].

A. Ghofrani et al. present an approach for assigning HVAC operation planning schemes to linked buildings with the goals of energy conservation and load balancing [49]. The aim is to utilize the thermal inertia of the structure in a periodic pattern by adjusting the temperature setpoints to a higher limit and then to a lower limit in order to avoid using air conditioning while the room is still within the human comfortable threshold. The purpose is to designate periodic temperature setpoints for a building cluster in order to lower the overall cooling electric demand at the lowest possible cost while maintaining a constant aggregate load shape. In addition, the influence of peak demand decrease on the grid and electricity generation costs, as well as its effect on society, are examined. The findings indicate up to a 12.5% decrease in energy usage and a 10% drop in peak demand for a neighborhood of 26 structures [49].

Moreover, N. Kampelis et al. analyzed the HVAC system in a smart, near-zero-energy industrial building using a genetic algorithm [50]. The research consisted of a tested building energy model, an energy cost model, and an optimization model for determining the optimal temperature set points for HVAC systems. The objective of the optimization is to determine the optimal trade-off between both the least daily energy cost and thermal comfort. Furthermore, incorporating the predicted mean vote into the aim function ensures that thermal comfort standards are satisfied [50].

J. Han et al. concentrate on an approach for deriving the optimum solution for the set-point temperature of an HVAC system utilized in office spaces, taking into account the thermal behavior and routine changes in weather circumstances, in order to create a comfortable indoor environment by reducing unnecessary energy consumption [51]. The operative temperature is utilized in the operation of the HVAC system, and the mean radiant temperature is forecasted with a 94% degree of precision using numerous regression analysis by utilizing internal thermal environment data and meteorological information. The regression equation was applied to generate a second equation for determining the appropriate set-point temperature. The simulation findings suggest that the HVAC system management with the new set-point temperatures determined using the developed formula increases thermal comfort by 38.5%. Besides, this research revealed that a cooling set-point temperature considers both the structure's thermal features and weather circumstances and efficiently boosts summertime indoor thermal comfort [51].

After analyzing the above literature gaps, HVAC play an essential role in the comprehensive implementation of nZEB as HVAC is responsible for most of the energy consumption in residential buildings. However, several researchers used Eppy’s script (python language tool) as a resource to support the resolution of this issue [52-56]. Therefore, to make it more convenient, a python script will be written or created to change the components, temperature, or other things in the HVAC system design for the buildings by using simulation tools (DesignBuilder, EnergyPlus, and eppy script) to fill the research gap. Though, in this research, the energy efficiency, comfort levels, and economic feasibility of several commercially available HVAC systems for a residential net-zero-energy building (nZEB) are evaluated. Although for getting a better active solution with the help of the eppy scripting tool, the set-point manager temperature (heating only) has been changed to achieve the aim of this study. Also, this master thesis aims to develop a methodology to identify the optimal operation of different HVAC system configurations for different climate conditions and building typologies.

2 Objectives

The HVAC system accounts for the most extensive percentage of total energy consumption in residential buildings. This system also plays a significant part in the large-scale deployment of nZEBs. This chapter, however, focuses specifically on the objectives of this master's thesis. This study assessed the energy efficiency, comfort levels, and economic viability of commercially available HVAC solutions for a residential nZEB. The goal of this research is primarily based on an in-depth investigation of the annual energy consumption values for newly constructed residential structures in terms of the nZEB. Also, this study aims to develop a methodology to identify the optimal operation of different HVAC system configurations for different climate conditions and building typologies. The following two types of objectives i.e., **General Objectives (GO)**, and **Specific Objectives (SO)** has been set to primarily in this study to get the desired outcome.

To accomplish the purpose of this master thesis, an investigation has been conducted on a reference building that is situated inside the five climatic zones that are found inland in Spain **(GO1)**. An accurate representation of nZEB can only be achieved by active systems or Energy Supply Systems (ESS). For the parametric study of the combinations, DesignBuilder (DB) building energy simulation software is used to include the combined impact of these solutions (**GO2**). For each location, it will be necessary to carry out several dynamic simulations to cover all of the cutting-edge solutions that are now being used in the building market of Spain. The goal is to find the most cost-effective ways to satisfy the main energy consumption demand under various limitations **(SO1)**. This study does not consider the need for cooling which is one of the limitations of the work, thus it can only be used for residential structures with thermal heating loads (such as space heating and domestic hot water (DHW)) **(SO2)**. Also, in the residential sector, there are still a very low number of buildings that are designed with cooling systems integrated into their construction. DesignBuilder (DB) building energy simulation will be used to design the case building with various HVAC scenarios and cases for the different climatic zones **(GO3)**. Though, the EnergyPlus (E+) program will be implemented as a building's HVAC system to model and estimate the building's heating demands in this study **(SO3)**.

In addition, E+ software is used to identify cost-effective HVAC solutions and to calculate the potential for energy-efficient heating systems **(SO4)**.

E+, a strong building energy modeling software, and eppy script, a powerful Python toolkit, form the engine of the adaptive heating design approach's automated optimization process **(SO5)**. The primary goal of this investigation will be accomplished if the following steps are carried out as planned: (i) selection of the weather file; (ii) modification of the input data; (iii) launch of the simulation from Python; and (iv) reading of the files containing the results of the simulation. Also, considering the different weather conditions, the heating loop (set point manager temperature, and heating loop temperature) needs to be modified in the input data, and this change will help reduce the building's annual energy consumption (electricity, natural gas, and other fuels) **(SO6)**. In summary, compared to previous highly efficient static systems investigated in this work, the suggested system has the potential to drastically cut yearly building electricity and natural gas usage.

3 Methodology

The main purpose of this chapter is to discuss the methods used to achieve the objectives of this study. The following three-step approach has been used primarily in this study to get the desired outcome. Firstly, the DesignBuilder (DB) software has been used to design the reference building and HVAC system designing of that reference building **(GO)**. After that, the reference building's DB file (.dsb) has been exported to the EnergyPlus (E+) file (.idf) format. Finally, the parameters of that exported .idf file have been edited or modified using eppy scripting in Python language (PyCharm software) **(SO)**. Figure 3.1 shows the principle working process diagram of the master thesis work. However, the details description of all necessary methods has been elaborated in the following part of the book.

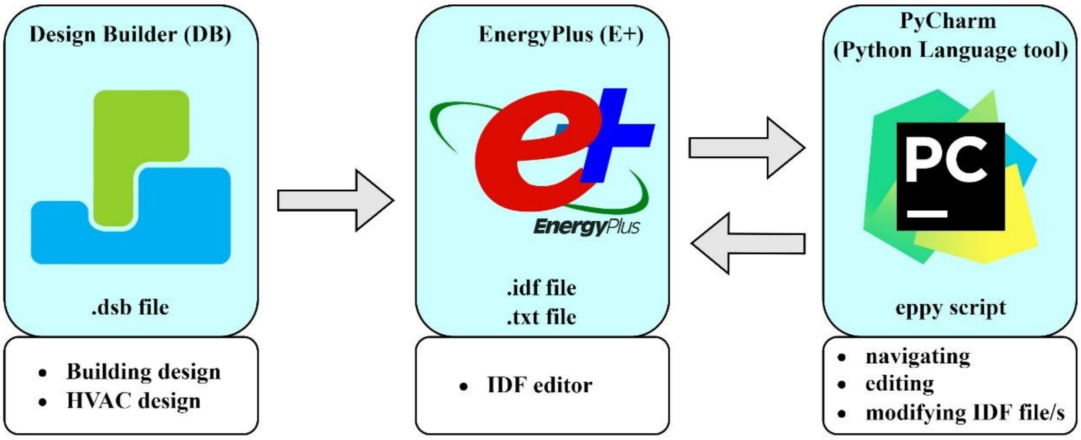


Figure 3.1: Principle working process diagram of the study

3.1 DesignBuilder™ (DB) Software

The DesignBuilder (DB) software is an integrated collection of high-productivity tools that may aid with the design of sustainable friendly buildings and help users earn credits with environmental certification programs like LEED and BREEAM [57]. DB is used by leading service engineers, architects, energy modelers, and HVAC engineers to make design decisions that maximize energy efficiency, comfort, and cost. By incorporating the design into DB's model, precise statistics on energy use, comfort, cost, and daylight performance can be obtained to aid in the process of making those crucial design choices.

3.1.1 Building design

To complete this study, it was first necessary to design a building, based on which it was possible to complete all the next necessary steps **(GO1)**. However, the main objectives to design a building using DB are including the energy performance of a building, calculating heating/cooling loads (evaluating the building energy performance, sizing/defining the building energy systems) **(SO1, SO2)**, energy assessment (evaluating the energy demand or the energy consumption, associated costs) **(SO1, SO2)**, thermal comfort and Indoor Air Quality (IAQ) assessments **(GO1, GO2)**. However, to design a building in DB, some aspects like local weather particularities (seasons, sun, wind, etc.) **(SO5)**, Orientation (of the building), Compacity, Areas or ratios of Opaque envelope, glazing, doors, Zoning or classification by similar thermal conditions, Space uses (activity types), Construction materials (conductivity, density, thermal mass, etc.), Surrounding (urban or natural context), floor and height, etc. are needed to be taken into consideration **(GO3)**.

3.1.2 HVAC design

After the completion of the building design, the HVAC design was added to the building. With compact HVAC, it's easy to get an in-depth look at popular heating and cooling systems. For the HVAC design, different retrofitting options were used to select the best HVAC template for the reference building. In DB, HVAC systems are constructed by connecting pre-defined air and water distribution loops and zones to make entire systems [39]. To create distribution systems, the air and water loops link various HVAC components through pipes or ducts. They may be changed to include any extra components and linked to other loops or heating, cooling, or ventilation equipment in zones to complete systems.

Zones are grouped to facilitate the use of the same HVAC equipment in many zones. Different equipment ratings are available for each zone in the group. There is no need to identify separate equipment and connections for each zone in a group, but each zone may still have its own set of equipment attributes. This considerably simplifies HVAC schematic construction. Setpoint managers are included in the pre-defined loops, allowing the loop to execute automatically without any extra input. Setpoint managers, on the other hand, may be added to the different loops to allow the system to be customized. It is possible to change data related to all loops, zones, and their associated components using dialog boxes. An E+ simulation for the integrated building and HVAC system model may be run after the necessary loop connections to connected equipment and the placement of loops, zone groups, and setpoint managers **(SO4)** [58].

3.1.3 DSB (.dsb) file

DB saves all of its primary model data in a single file that has the .dsb extension [59]. This makes it simple for users to share project models along with the accompanying outcomes with their coworkers and customers. A .dsb file contains:

- Building geometry
- Model data settings
- HVAC data
- Model components and templates
- Any user-defined weather files
- Any user-defined textures
- All of the findings for heating and cooling design, simulation, daylighting, cost/carbon, optimization, and Computer Fluid Dynamics (CFD) (including all project variations) [60].

However, as in the DB, simulated files are saved in .dsb format, so if the user wants to work in EnergyPlus (E+) software with the same data so it is necessary to change the file format from .dsb format to .idf format **(SO5)**. A .skh backup file will be created if DB does not shut down properly and cannot save, then DB will ask whether the user wants to retrieve this data the next time opened the .dsb file.

3.2 EnergyPlus™ (E+) Software

EnergyPlus™ (E+) is a whole building energy simulation software that engineers, architects, and academics use to simulate both energy consumption and water usage in buildings [61]. Moreover, this modeling is used for heating, cooling, ventilation, lighting, plug and process loads, and many more [62]. E+ has several impressive features and capabilities, such as:

- Integration of thermal zone conditions and HVAC system reaction into one integrated, simultaneous solution that does not presume the HVAC system can fulfill zone loads and can simulate unconditioned and under-conditioned areas.

- Condensation and thermal comfort estimates may be made using a heat balance-based solution to the effects of convection and radiation.
- Sub-hourly, user-definable time steps for thermal zone interactions with the environment; time steps that vary automatically for thermal zone interactions with HVAC systems. These features enable EnergyPlus to simulate systems with rapid dynamics without sacrificing simulation speed for accuracy.
- Air movement across zones is taken into consideration in this combined heat and mass transfer model.
- Controllable window blinds, electrochromic glazing, and layer-by-layer heat balancing are a few of the advanced fenestration models included in this category.
- Illuminance and glare measurements for reporting visual comfort and controlling lighting.
- HVAC is based on components that may be configured in both traditional and unique ways.
- A significant variety of pre-programmed control techniques for the heating, ventilation, and lighting systems, as well as an extendable runtime scripting framework for user-defined control.
- Import and export capabilities for functional mockup interfaces to facilitate co-simulation with other engines.
- User-defined reports with time resolutions ranging from yearly to sub-hourly and energy source multipliers are available in addition to the standard summary and comprehensive output reports.

However, the E+ application is run from a console and receives input from the user before writing the results to text files. It is included with several tools, one of which is called IDF-Editor, which offers a straightforward interface like that of a spreadsheet and is used to create input files.

3.2.1 IDF (.idf) file

The building and HVAC system simulation data is stored in an ASCII file called the input data file (IDF) [62, 63]. When installing E+, the user will find a large number of sample files. Also included in the "ExampleFiles.xls" spreadsheet is a list of each file's characteristics in columns.

3.2.2 IDD (.idd) file

The *input data dictionary*, often known as the IDD, is a text file encoded in ASCII that contains a list of all of the potential E+ objects as well as a specification of the data that is required by each item [54, 64]. A comparison may be made between this file and the DOE-2 keyword file. A comprehensive explanation of the input data dictionary may be found in the Guide for Interface Developers document.

Working with E + necessitates the use of idf files (those with the extension *.idf). The .idd file is another critical component that contains the definitions for all of E+'s objects. The .idd file of the .Esch’s version of E+ is different. Therefore, eppy must know which .idd file to utilize. A script or application can only make use of a single .idd file at a time. This indicates that once the .idd file has been chosen, it cannot be altered in any way. Before beginning work on eppy, a file with the extension .idd is chosen to begin with. Because an error message will be generated by eppy if any of the guidelines listed above are broken when using the program.

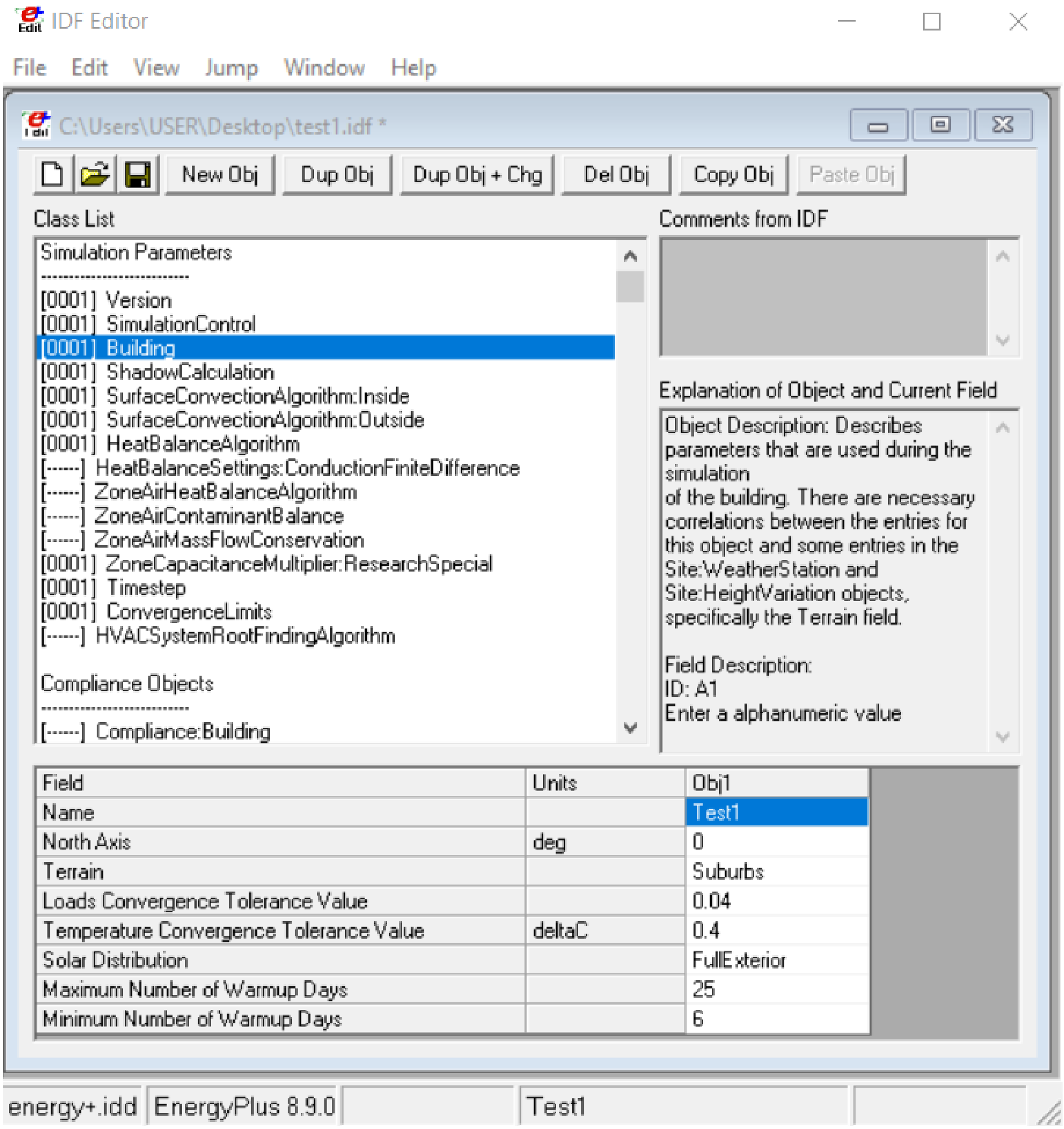
3.2.3 IDF editor

E+ provides the user with several different choices for generating input files. The next section of this book describes the features of the IDF editor that are included with the installation of E+. The E+ Data Dictionary (IDD) is read by the IDF Editor, which is a straightforward and "intelligent" editor that enables the generation and updating of E+ Input Files (IDF) [65, 66]. Either a shortcut that was produced during the installation process and placed in the main E+ directory or EP-Launch may be used to execute the program. Figure 3.2 shows the IDF editor screen.

IDF Editor is a component of the E+ installation that is completely optional. Users who are looking for a straightforward method of generating or updating E+ input data files (IDF) may make use of IDF Editor, which offers this functionality. Although certain numeric fields are marked if they are out of range and some text fields are highlighted if they include an invalid reference, the IDF Editor does not validate the validity of the inputs that are provided. The user should consult the Input/Output Reference document before attempting to create an IDF file so that they are aware of the rules and instructions that must be adhered to.

However, to complete the next steps of this study, the .dsb file has been exported to the .idf file so that the file can be edited or modified through E+'s IDF editor **(SO3, SO4,**

and SO5). In addition to IDF format files, it is also possible to save/edit/modify files in .text format. Also, for the next steps (eppy script, python), the file must be available in both .idf and .text format.



Simulation Parameters

[0001] Version
[0001] SimulationControl
[0001] Building
[0001] ShadowCalculation
[0001] SurfaceConvectionAlgorithm:Inside
[0001] SurfaceConvectionAlgorithm:Outside
[0001] HeatBalanceAlgorithm
[------] HeatBalanceSettings:ConductionFiniteDifference
[------] ZoneAirHeatBalanceAlgorithm
[------] ZoneAirContaminantBalance
[------] ZoneAirMassFlowConservation
[0001] ZoneCapacitanceMultiplier:ResearchSpecial
[0001] Timestep
[0001] ConvergenceLimits
[------] HVACSystemRootFindingAlgorithm

Compliance Objects

[------] Compliance:Building

Object Description: Describes parameters that are used during the simulation of the building. There are necessary correlations between the entries for this object and some entries in the Site:WeatherStation and Site:HeightVariation objects, specifically the Terrain field.

Field Description:
ID: A1
Enter a alphanumeric value

Field	Units	Obj1
Name		Test1
North Axis	deg	0
Terrain		Suburbs
Loads Convergence Tolerance Value		0.04
Temperature Convergence Tolerance Value	deltaC	0.4
Solar Distribution		FullExterior
Maximum Number of Warmup Days		25
Minimum Number of Warmup Days		6

energy+.idd | EnergyPlus 8.9.0 | Test1

Figure 3.2: IDF editor screen (screenshot)

3.3 Eppy (eppy) Script

Eppy is a scripting language that can be used for E+ output files as well as E+ idf files [54, 67]. Python is the computer programming language that is used to write Eppy. As a consequence of this, it makes full use of the many data structures and idioms that are accessible in the Python programming language. Through the use of eppy, it is possible to explore, search, and alter E+ idf files programmatically. Scripting languages provide the user the ability to achieve the following things:

- With a few lines of eppy code, it can possible to make a lot of modifications to an idf file.
- When making modifications to an idf file, use conditions and filters.
- Multi-idf file edits are supported.
- Read the results of an E+ simulation run in the form of output files.
- Create the input file for the next E+ simulation run based on the results of the previous experiment

3.3.1 Eppy installation

Some packages and sub-packages had to be installed in addition to the eppy script to complete this study **(SO3, SO4, and SO5)**. First of all, this step is started by installing PyCharm IDE (pycharm-community-2021.3.2) software so that the rest of the work can be done by coding Python. After that, to install eppy in the next step, this command has been run on the terminal:

- $ pip install eppy

In the next step, the required packages and sub-packages has been installed by the following path:

PyCharm > File > Settings > Project: -- > Python Interpreter > Click on + Sign > Type package names (i.e., eppy, hvac builder, etc.) > Click Install Package

To conduct the study given packages have been installed:

- **munch:** python dictionary that provides attribute-style access.
- **soupsieve:** A CSS selector library for BeautifulSoup4 is called SoupSieve. It tries to give contemporary CSS selectors for choosing, matching, and filtering.
- beautifulsoup4: The Beautiful Soup library is a Python package that extracts data from HTML and XML documents [68].
- **pydot:** Pydot is an interface for the program that is responsible for drawing, which is called a dot (a component of Graphviz) [69]. Graphviz may not have been installed if users did not use the default installation method for pydot.
- **pyparsing:** The client code may create the grammar directly in Python by using the pyparsing module, which offers a library of classes that the client code can utilize.

- **pytest:** The syntax of the pytest package is much simpler than those of other Python testing tools like unittest and nose [70]. This helps the pytest package stand out from the competition.
- **tinynumpy:** This module's goal is to make it possible for libraries that rely on numpy but do not make extensive use of array processing to make numpy a dependency that is either required or optional [71].
- **six:** Six offers straightforward tools for bridging the gap between Python 2 and Python 3's defining characteristics [72]. It is meant to support codebases that operate without change on both Python 2 and Python 3, which is why it was designed this way. Since there is just a single Python file that makes up six, incorporating it into a project is a breeze.
- **decorator:** Decorating a function or class in Python is a highly strong and valuable technique since it enables programmers to change the behavior of the function or class. Using decorators may expand the behavior of a wrapped function without making any permanent changes to the wrapped function itself.
- **lxml:** It's a Python package that makes it simple to work with XML and HTML files, and it can also be used to extract data from the web.
- **__future__:** The __future__ module is a Python built-in that is used to inherit new features that will be available in the latest Python versions [70]. This module contains all of the new features that were not available in the previous version of Python.
- **nbsphinx:** nbsphinx is an extension for Sphinx that offers a source parser for files with the *.ipynb extension [73].
- **pip:** PIP is the Python programming language's default package manager [74]. Users will be able to install and manage packages that aren't a part of the Python standard library. Installing Python packages is easiest when done with the help of the pip tool. For instance, if a user has to install an external package or library, such as requests, the user must first install pip to do this task. Under the current conditions, it is feasible that the user will not need the usage of any external libraries. On the other hand, consumers could need it soon.
- **bump2version:** A little command-line program to make releasing software easier by incrementing all version strings in existing source code.

- **wheel:** There's a good probability that a wheel was used to speed up the installation of a Python package that was installed via pip [75]. The Python environment relies on wheels to ensure package installations go smoothly. These characteristics allow for a faster installation of packages [76].
- **watchdog:** In Python, there are several techniques to keep track of directory changes. The watchdog module is a good example of this [77]. In keeping with its name, this module monitors the specified directory and may send an alert whenever a file is added or modified.
- **flake8:** It is an excellent toolbox for inspecting the code base for the correctness of coding style (PEP8), programming faults (such as "library imported but unused" and "Undefined name"), and cyclomatic complexity [78].
- **tox:** tox is a command-line virtualenv management and testing tool that may be used to verify that packages are properly installed on a variety of Python versions and interpreter environments.
- **coverage:** Code coverage may be measured using Coverage.py, a Python utility. Code that might have been run but wasn't may be identified by monitoring the program, and then analyzing the source code [79]. When evaluating the efficacy of tests, it is common practice to employ coverage measurement.
- **Sphinx:** Sphinx is a tool that generates documents from source code [80].
- **twine:** The twine Python module is used to securely upload data to PyPi. New and current projects may submit their source and binary distribution artifacts using this tool [73].
- **pytest-runner:** pytest-runner is dependent on setuptools features that have been marked as obsolete and rely on features that cause security safeguards in pip to malfunction [70].
- **black:** Black is a Python code formatter that does not make concessions. Users who make use of it agree to give up control over the specifics of the hand-formatting process when they do so [76]. In exchange, black provides its users with increased speed, determinism, and immunity against pycode-style warnings about the format. Users will be able to conserve time and mental resources for more significant issues.
- **requirement:** The most basic explanation for a requirements file is that it is just a list of pip install parameters that have been saved in a file [81]. It is

> common practice to make use of Requirements Files to establish the prerequisites for a full Python environment. It is put to use in the process of installing all of the dependent components on a different computer so that they are compatible with one another. Second, it simplifies the process of collaborating on projects with other people. They execute the project without encountering any issues as a result of installing the Python modules that are stated in the requirements file.

However, after successfully installing such packages and sub-packages, the next step is to edit the IDF file by using Python language with the help of EPPY scripting **(SO3, SO4, and SO5)**.

3.3.2 Eppy (modifying idf files)

After installing the relevant packages and sub-packages, the .idf files are edited or modified in the PyCharm software using Python language. In this case, first, the necessary packages need to do import, the location of the required .idf and .idd files are marked, and the location of the weather data (.epw) file is also declared. In addition, different weather data, and scripts for different temperature replacements have been reported. Then, by running the python “for loop” chain, the required unit (temperature of the heating system) is changed by marking the required parameters in it **(SO5)**. Finally, the location of the new .idf files and the required output results are saved in the newly assigned location. However, the python script has been added to the Appendix section of this master thesis book.

It was stated at the beginning of this chapter that the three-step method was initially used in this study to obtain the desired results. Firstly, the DesignBuilder (DB) building energy software is used to design the case building. Also, HVAC systems have been designed for different locations and scenarios for similar case buildings. Subsequently, the parameters of the .idf file have been edited or modified in Python language (PyCharm software) using eppy scripting by exporting the DB file (.dsb) of the case building to EnergyPlus (E +) file (.idf) format. So, in summary, it is clear that by following the aforementioned methods for this work the required objectives of the work have been achieved.

4 Case Study

The main purpose of this chapter is to discuss in detail the case building, HVAC design, and heating system design, considering the Spanish climatic zones. Code. The evaluation is carried out on a typical residential structure, which, owing to the qualities that identify it most prominently, is used as a reference building for the evaluation. Building energy simulation software called DesignBuilder (DB) is used to simulate the reference building. This software makes it possible to calculate the energy performance of the building over the course of an entire year.

Considering the Energy Supply System (ESS), a set of alternative scenarios is defined, where the Energy Saving Measure (ESM) is kept unchanged (not taken into account). Specifically, 10 ESS options have been preselected. These alternatives include the generation of both electrical and thermal energy. Because certain circumstances (such as roof availability) restrict the number of feasible combinations, the designs that may be implemented are limited to 30 possibilities. These scenarios are modeled for Spain's 5 inland climate zones, notably Bilbao (climatic zone C), Almeria (climatic zone A), Valencia (climatic zone B), Madrid (climatic zone D), and Burgos (climatic zone E). These findings are dissected in great depth and contrasted with the prerequisites outlined in the Spanish Technical Building Code [82], which at the moment serves to establish the nZEB standard in the nation.

4.1 Spanish Technical Building Code

There are a number of Basic Documents that make up the Spanish Technical Building Code. Depending on the building type, activity, and climatic zone, there are several energy performance (DB-HE) standards that must be reached. Several parts of the DB-HE address the needs of new construction projects. The subsections that are relevant to the case study are discussed further down in this section. Total primary energy consumption, as well as non-renewable energy consumption, are both restricted for new residential structures. The HE0 subsection determines this consumption limit, and it varies according to the climate zone in which the building is situated (Figure 4.1). Table 4.1 provides a summary of these limitations. The non-renewable primary energy consumption restriction is precisely double the maximum primary energy consumption permitted.

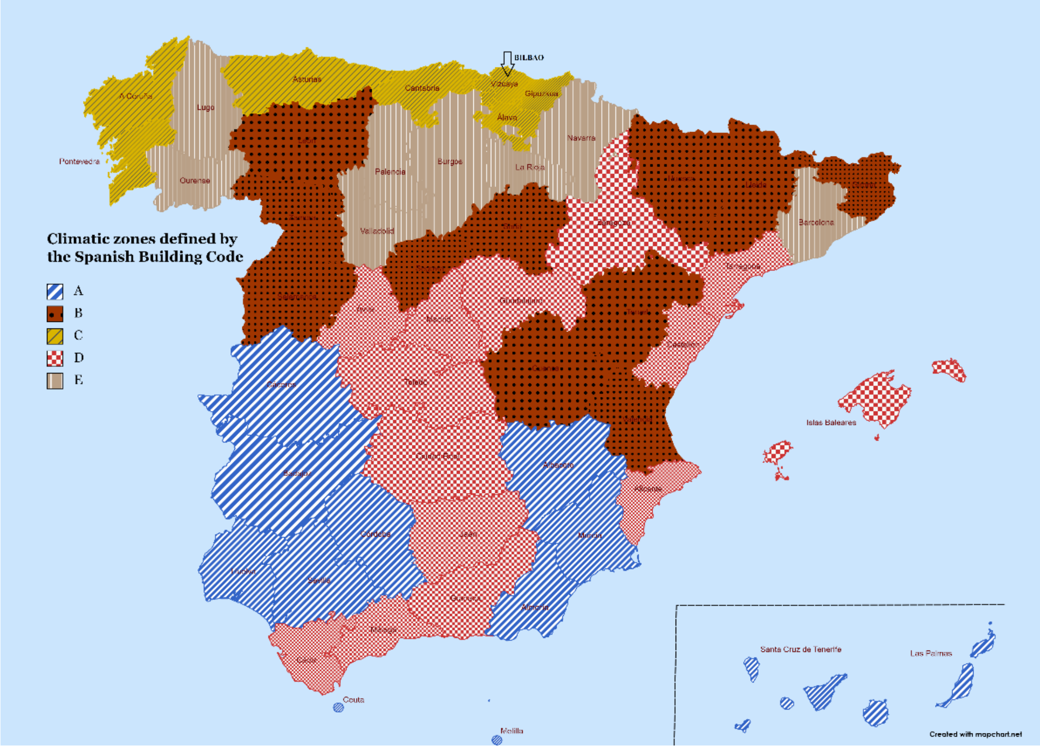


Figure 4.1: Climatic zones defined by the Spanish Building Code

Table 4.1: Primary energy consumption limits for new buildings under the Spanish Technical Building Code (HE0)

Climatic Zone	A	B	C	D	E
City	**Almeria**	**Valencia**	**Bilbao**	**Madrid**	**Burgos**
Non-renewable primary energy consumption (kWh/m^{2}y)	25	28	32	38	43
Total primary energy consumption (kWh/m^{2}y)	50	56	64	76	86

In addition to limiting energy consumption, new residential structures must also restrict their energy demand. In contrast to the energy consumption, the HE1 subsection is responsible for determining the maximum value of thermal transmittance that the envelope components are permitted to assume. The maximum amount of delivery that is necessary for the outer material for the case building is, however, detailed in Table 4.2 below.

There is an HE4 subsection that determines the minimum amount of thermal renewable energy needed to satisfy the domestic hot water demand. It is recommended that the contribution from thermal renewable energy sources be at least 70%, or 60%, in buildings with overall domestic hot water demand (DHW) demands that do not exceed 5000 l/d, as is the case for most buildings and the case study selected (see Section 4.2). A CO2 concentration of more than 900 ppm is prohibited under the HS3 subsection's ventilation regulations. Specifically, volumetric airflows are established based on the size and utilization of the areas in the home.

Table 4.2: Maximum transmittance for the envelope elements for case building

Envelope Elements		**Maximum Transmittance**
External walls and floors (W/m^2°C)		0.49
Roof in contact with outside air (W/m^2°C)		0.40
Partitions in contact with non-habitable spaces (W/m^2°C)		0.70
Windows (W/m^2°C)		2.10
Doors (W/m^2°C)		5.70
Floors between rooms with the same use (W/m^2°C)		1.35
Walls between rooms with the same use (W/m^2°C)		1.20
Floors and walls between areas with different uses (W/m^2°C)		0.95
Total primary (kWh/m^{2}y)	**V/A≤1**	0.73
	V/A≥1	0.81

4.2 Reference Building

The reference building is situated in Ermua, near Bilbao (climate zone C), assuming the same climatic conditions. The structure has a total height of 25 meters and a conditioned area of 1,883 m^3 with a total of 22 dwellings on 8 floors (including the ground floor). The reference building was chosen as an example of a heavily populated metropolitan area because of its representative nature. The north front of the building is completely encircled by neighboring structures. Since other buildings will benefit from larger solar gains, which raise the profitability of renewable energy sources integration and improve the cost-optimality of the structure, using this one as a reference building might be considered a prudent assumption. Figure 4.2 shows the DB 3D model of the building.

The structure is now in the design process and complies with all of the requirements outlined in the Spanish Technical Building Code for newly constructed residential structures (Table 4.2). To be more specific, Table 4.3 provides a summary of the thermal transmittance of the various components that make up the reference building.

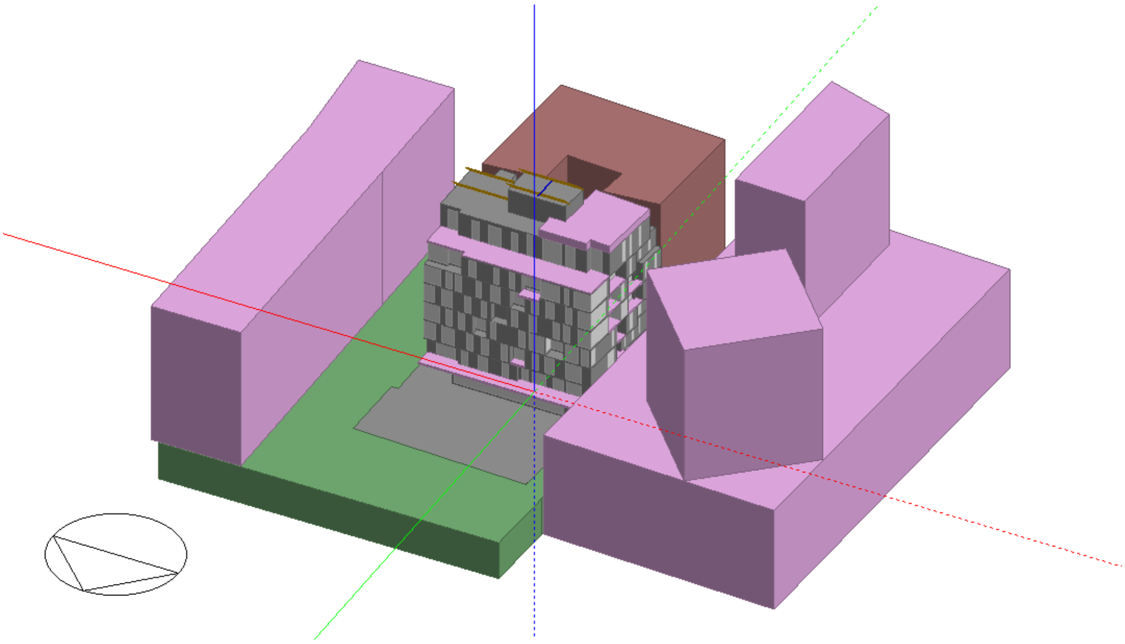


Figure 4.2: 3D model of the building in DesignBuilder (DB)

Table 4.3: Summary of thermal transmittance of building elements of the reference building

Building component	Transmittance (W/m^2K)
Underground floor	0.568
Floor between underground spaces	0.620
Floor between underground floor and ground floor	0.611
Floor between dwellings	0.460
Roof	0.259
Façade	0.252
Walls between dwellings and common areas	0.631
Walls between dwellings	0.346
Windows and doors	2.520

According to the requirements that are used for energy performance certification in Spain, parameters such as occupancy, illumination, and equipment were determined [83]. These parameters, together with heating set point temperatures and ventilation ratios, were also taken into consideration. Following the submission of the HS3 application, the minimum amount of ventilation that is required for each home was determined to be 7.6 l/s.

The reference building's ESS is made up of two natural gas-fired condensing boilers, each of which is scaled to fulfill the peak load requirements for both space heating and domestic hot water generation, the latter of which is supplemented by a solar thermal collector system to meet 60% of the requirements set out by the Spanish Building Technical Code (Section 4.1). Radiant floors are often used to heat spaces, which makes them ideal for applications requiring lower temperatures. Electricity requirements are met by the local power supply network. To comply with the Technical Building Code, only the active systems' electricity usage is taken into consideration. The availability of roof space is a critical factor to consider while putting in place renewable energy sources. There is just 162 m^2 of available space in this particular situation for this use.

4.3 Definition of Scenarios

The investigation is carried out for several different situations, each of which is produced by the concurrent use of active (ESS) solutions.

Configurations of energy storage systems (ESS) are produced by combining various energy conversion units, which ultimately results in a series of scenarios that are outlined in Table 4.4. In addition to the factors that are given below, the economic analysis additionally takes into account a number of auxiliary factors (Section 4.4). The 30 different possibilities depending on the 3 different temperatures (45 °C, 60 °C, and 65 °C) of the setpoint manager of the heating system. However, the aforementioned 30 possible alternatives were identified for each location from the combination of the 10 distinct ESS over the reference building, resulting in a total of 150 simulations.

Table 4.4: Summary of Energy Supply Systems (active solutions)

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Condensing Gas Boiler (heating)	■					■				
Non-Condensing Gas Boiler (heating)		■			■		■			■
Condensing Gas Boiler (DWH)	■					■	■			
Non-Condensing Gas Boiler (DWH)		■				■	■			
Air-source heat pump - ASHP (heating)			■					■		
Air-source heat pump - ASHP (DWH)			■					■		
Ground-source heat pump - GSHP (heating)				■					■	
Ground-source heat pump - GSHP (DHW)				■					■	
Biomass - BIO (heating)					■					■
Biomass - BIO (DWH)					■					■
Solar collector thermal CTE - STm	■					■				
Solar collectors thermal 100% - STM		■					■			
Distribution Pumping [Constant Volume Flow] (heating)	■	■	■	■	■					
Distribution Pumping [Variable Volume Flow] (heating)						■	■	■	■	■

4.4 Technical Analysis

This section is focused on the technical analysis of the study which is mainly focused on the proposed HVAC system design scheme. The investigation is carried out for several different situations (Table 4.4), each of which is produced by the concurrent use of active (ESS) solutions.

4.4.1 Main features of HVAC installation

DB building energy simulation software [84], a graphical user interface for EnergyPlus (E+) solver [54], is used to model each scenario, as mentioned before. To be more specific, the "Detailed HVAC" model option was chosen to be employed. This option enables the exhaustive design and simulation of the integrated HVAC components that were used to construct each ESS that was described in Section 4.3. As an example, the S1 setup, as it is described in DB, is shown in Figure 4.3 for the climatic zone C (Bilbao). This design depicts the loops for space heating, DHW, and ventilation.

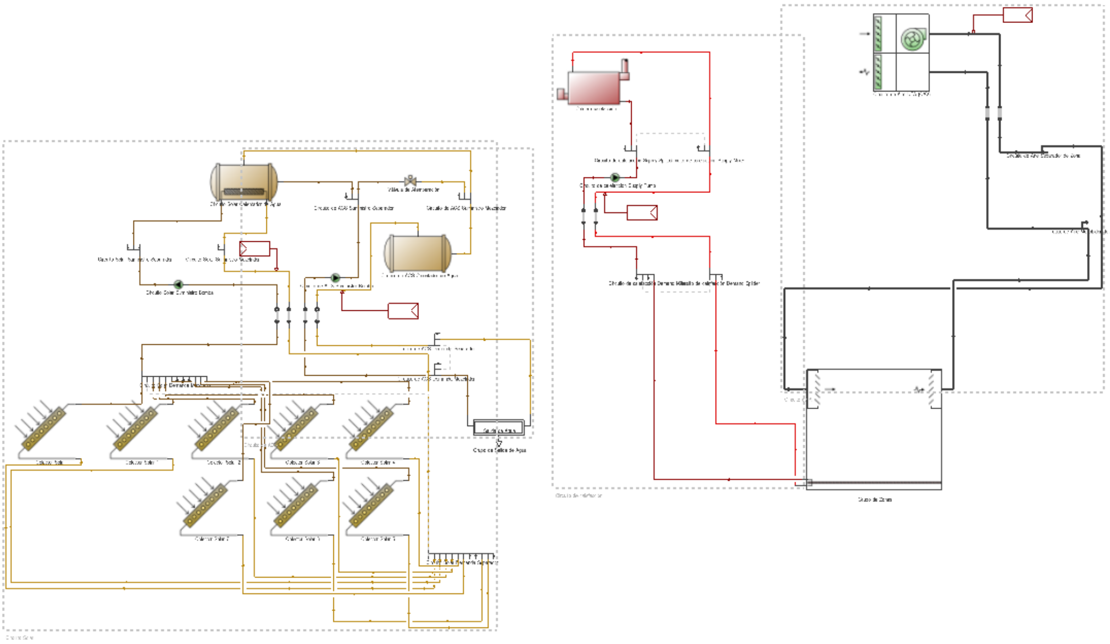


Figure 4.3: HVAC scheme for the S1 configuration

- **Hot Water Loop (HW Loop):** In this loop, a condensing gas boiler, an HW supply pump (constant volume flow), and a set point manager have been used for heating production. The set point manager of the HW loop scheduled that the hot water flow rate is 45 °C (always). Also, in the set point manager, the sizing of the "Design of the exit temperature (°C)" keeps the same as the set-point manager temperature, i.e., 45 °C, and the "Loop design temperature difference (deltaC)" has kept at 10 °C. This value is expected to meet the thermal comfort of the building.

- **Domestic Hot Water Loop (DHW Loop):** In this loop, a water heater, a DHW supply pump, water outlet group, and a set point manager have been used for heating production. The set point managers of the DHW loop scheduled that the hot air flow rate is 60 °C. This value is expected to meet the thermal comfort of the building.
- **Air Loop:** In this loop, an Air loop Air Handling Unit (AHU) Constant Air Volume (CAV) and a set point manager have been used for air handling. The Air Loop set point manager is 14 °C that sends air to the zones. This value has chosen because the temperature of comfort is 11 °C - 16 °C.

  Connection between the HW loop and the Air loop: The demand side of the HW loop and the HW loop splitter became attached to the air loop heating coil before sending the air to the zone.
- **Solar Loop:** In this loop, eight solar collector (Complete Thermal Exchange (CTE) technology), a water heater, a DHW supply pump, and a set point manager have been used for heating production. The set point managers of the DHW loop scheduled that the hot air flow rate is 55 °C.

4.4.2 Energy assessment

For the sake of this study, ESS is made up of reference technologies, the summary of which can be found in Table 4.5. These technologies' efficiencies under nominal circumstances are shown there. For the simulations, DB takes into account the performance curves of each technology to derive the real efficiency from the efficiency under nominal circumstances. It is important to keep in mind that the size of each ESS has to be determined according to the energy requirements of each instance, which are determined by the heating load. In turn, they are dependent on the climatic zone as well as the ESM scenarios. Therefore, it is essential to conduct an appropriate sizing for each component of the ESS that is included in the scenarios that are described in Table 4.4.

Table 4.5: Efficiency of the technologies under consideration

Energy conversion unit	Nominal efficiency
Condensing Gas Boiler	$\eta_t = 95\%$
Non-Condensing Gas Boiler	$\eta_t = 80\%$
Air-source heat pump (ASHP)	$COP = 3.2$
Ground-source heat pump (GSHP)	$COP = 4$ - 4.8 (Depending on the case)
Biomass Boiler (BIO)	$\eta_t = 85\%$
Solar thermal collector (ST)	$\eta_t = 78\%$ (corrected by the loss coefficients)
Cogeneration unit (CHP)	$\eta_t = 70\%$ $\eta_e = 27\%$
Water pump	$\eta_m = 90\%$
Ventilation fan	$\eta_m = 75\%$
Heat recovery system (HR)	$\eta_t = 75\%$

Sizing is dependent on whether the technology under discussion is employed just for DHW generation or for space heating and/or DHW. The heating load calculation technique is used to fulfill the demand for space heating and is dependent on the construction features and location of the structure. DB's 'Autosize' tool uses the ASHRAE heating load calculation technique to size condensing gas (S1 and S6), non-condensing boiler (S2 and S7), and biomass boiler (S5 and S10) [85]. When it comes to the other energy supply units, such as aerothermal (S3 and S8) and geothermal heat pumps (S4 and S9), autosizing is not an option. Instead, these units must be manually created for each scenario, and the ASHRAE technique is used in this process as well. If DHW production is coupled to space heating (when the same technology provides both needs, i.e., S1 as appears in Figure 4.3), then space heating is provided through a thermal energy storage tank. This tank is charged by an additional thermal energy production that stores the surplus along with the instantaneous demand for space heating. The size of the tank is determined by the DHW peak load that determines the Spanish standard [86]. Since the DHW load is reported by the standard on an hourly basis, DHW discharges are often in the range of minutes. An additional thermal energy storage tank with a capacity of three hours has been constructed to accommodate any sudden surges that may occur. Furthermore, both types of distribution pumping (heating) have been used, such as constant volume flow (S1 to S5), and variable volume flow (S6 to S10).

E+ data files for the five chosen sites are used to execute annual hourly simulations, and total final energy consumption data for pumps, fans, and energy conversion equipment are aggregated for a whole year. The weighting factors released by the Spanish Ministry for the Ecological Transition are used to transform final energy statistics into renewable and non-renewable primary energy [87]. Table 4.6 provides an overview of the study's weighting parameters. Despite the possibility of negative values, it is believed that the ESS's electricity output is deducted from its power consumption. Due to the fact that energy generated on-site or in close surroundings is used, there is no need to purchase it from the local power grid. To support this approach, the Spanish self-consumption law mandates that renewable and high-efficiency cogeneration units be owned collectively by all users within a 500-meter circle around the power plant [88].

Table 4.6: Weighting factors to translate final energy to primary energy

Final Energy	Renewable Primary Energy	Non-renewable Primary Energy
Electricity	0.414	1.954
Natural gas	0.005	1.190

In summary, the case building was originally designed using DB building software located in Ermua, a town near Bilbao (climate zone C). By selecting 10 ESS options, the design of heating with the focus on the top confines itself to 30 possibilities, and these conditions are modeled for Spain's 5 indoor climatic zones. Finally, these developments are profoundly contradictory to the preconditions described in the Spanish Technical Building Code, which suggests that the system design will work to establish the value of nZEB.

5 Results and Discussion

This chapter summarizes the findings gained from the technology analysis of the 150 simulations stated in Chapter 5. As mentioned in previous chapters, for getting a better active solution with the help of the eppy scripting tool, the set-point manager temperature (heating only) has been changed to achieve the aim of this study. To make the analysis concise, data are presented in detail for the climatic zone C (Bilbao), for which the reference building was designed. Then the analysis is extended to the rest of the cities selected. The figures (graphs) represent the ESS scenarios, the annual energy consumption (kWh/m^2) for different scenarios (S1-S10) of heating system with the variation of set-point manager temperature, where the aqua bars indicates the Annual Natural Gas (kWh/m^2) consumption, purple bars indicates the Annual Electricity (kWh/m^2) consumption, orange bars indicates the Other Fuels Annual (kWh/m^2) consumption, and red bubbles (each bubble) with red line indicates the variation of temperatures (°C).

5.1 Result Analysis

Figure 5.1 (graph) and Table 5.1 represents that, for S1, when energy consumption is rapidly rising with the increase of the temperature for Climatic zone C (Bilbao).

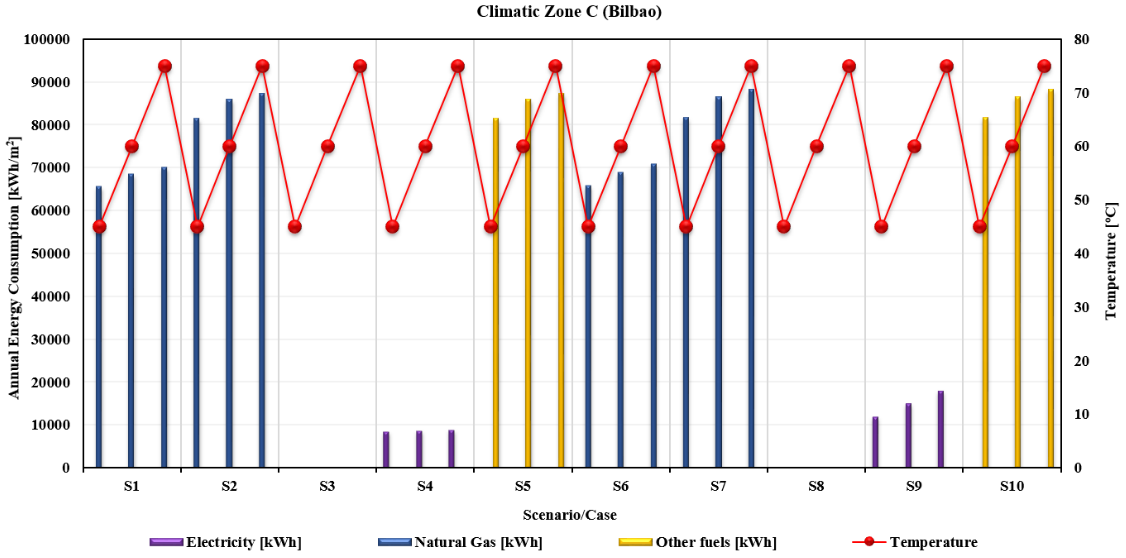


Figure 5.1: Annual energy consumption for climatic zone C (Bilbao)

The summers in Bilbao are mild and pleasant, the winters are very long, cold, rainy, and windy, and it is gloomy for a significant portion of the year. However, in HVAC design, if the set point manager's temperature is calibrated, the energy consumption will rise or decline proportionally [89]. On the other hand, in the case of other scenarios (after changing the HVAC design), energy consumption is also increasing and decreasing depending on the temperature variation.

Table 5.1: Annual energy consumption for different scenarios (for climatic zone C (Bilbao))

Scenario	**Temperature (°C)**	**Annual Energy Consumption (kWh/m^2)**		
		Electricity (kWh/m^2)	**Natural Gas (kWh/m^2)**	**Other Fuels (kWh/m^2)**
S1	45	14.45	65681.68	0
	60	14.90	68534.61	0
	75	15.08	70108.78	0
S2	45	14.38	81507.16	0
	60	14.82	85884.39	0
	75	15.00	87192.25	0
S3	45	0	0	0
	60	0	0	0
	75	0	0	0
S4	45	8473.9	0	0
	60	8754.97	0	0
	75	8884.08	0	0
S5	45	14.38	0	81507.16
	60	14.82	0	85884.39
	75	15	0	87192.25
S6	45	14.48	65802.48	0
	60	14.99	68971.26	0
	75	15.23	70870.9	0
S7	45	14.4	81664.74	0
	60	14.91	86445.91	0
	75	15.15	88167.52	0
S8	45	0	0	0
	60	0	0	0
	75	0	0	0
S9	45	11985.03	0	0
	60	15041.46	0	0
	75	17993.54	0	0
S10	45	14.4	0	81664.74
	60	14.91	0	86445.91
	75	15.15	0	88167.52

For scenarios S1 and S6, due to the use condensing boiler, in both the distribution pumping (constant volume flow (S1 to S5), and variable volume flow (S6 to S10)) method, the electricity consumption is between 14.45-15.23 kWh/m^2 and the natural gas consumption is in between 65681.68-70870.90 kWh/m^2. For the scenario of S2 and S7, due to the use non-condensing boiler, the electricity consumption is between 14.38-15.00 kWh/m^2 and the natural gas consumption is between 81507.16-88167.52 kWh/m^2. So, it can be observed that due to the use of non-condensing boiler gas consumption is rising whereas the other fuel consumption is zero for upper mentioned four scenarios (S1, S2, S6, and S7). After adding the Biomass Boiler (S5 and S10) with the non-condensing boiler, electricity consumption is almost similar to other scenarios (S1, S2, S6, and S7). But, natural gas consumption is almost zero and due to the use of biomass boilers, other fuel consumption is added to the cost with the range of 81507.16-88167.52 kWh/m^2.

For the rest of the scenarios (S3, S4, S8, and S9), due to the use of an air-source heat pump (S3 and S8), all types of energy consumption are zero. This is because the heat supply is lower, and also, air-source heat pumps can work at temperatures as low as -20 °C, and lose efficiency below 0 °C [90], so this type of system may require a large radiator to improve the system. On the other hand, due to the use of ground source heat pumps (S4 and S9), natural gas and other fuel consumptions are zero but the electricity consumption is rising high (8473.9-17993.54 kWh/m^2) compare to other aforementioned scenarios. In practice, this means that the energy consumption of the entire system is designed based on electricity, as a well-installed ground source heat pump can be 300-400% efficient in using electricity [91].

Now, for the rest of the climatic zones (A, B, D, and E), the annual energy consumption has changed depending on the weather as shown in subsequent graphs (Figure 5.2-Figure 5.5). Since the scenarios of HVAC design remain unchanged, so the energy consumption for the rest of the climatic zone has been obtained by using the same practices. However, Figure 5.2 (graph) represents annual energy consumption for the different scenario of climatic zone A (Almeria). The climate characteristics of Almeria in summers are brief, hot, muggy, and largely clear, while the winters are lengthy, chilly, dry, windy, and partially overcast.

Figure 5.3 (graph) represent annual energy consumption for the different scenario of climatic zone B (Valencia). In Valencia, the summers are lengthy, chilly, windy, partly overcast, and dry regardless of the season.

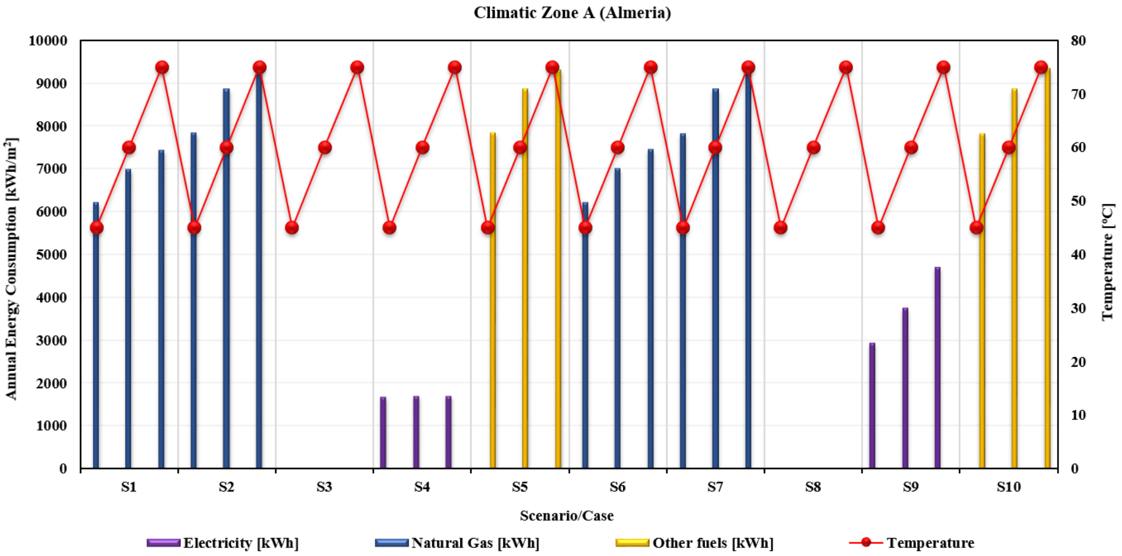


Figure 5.2: Annual energy consumption for climatic zone A (Almeria)

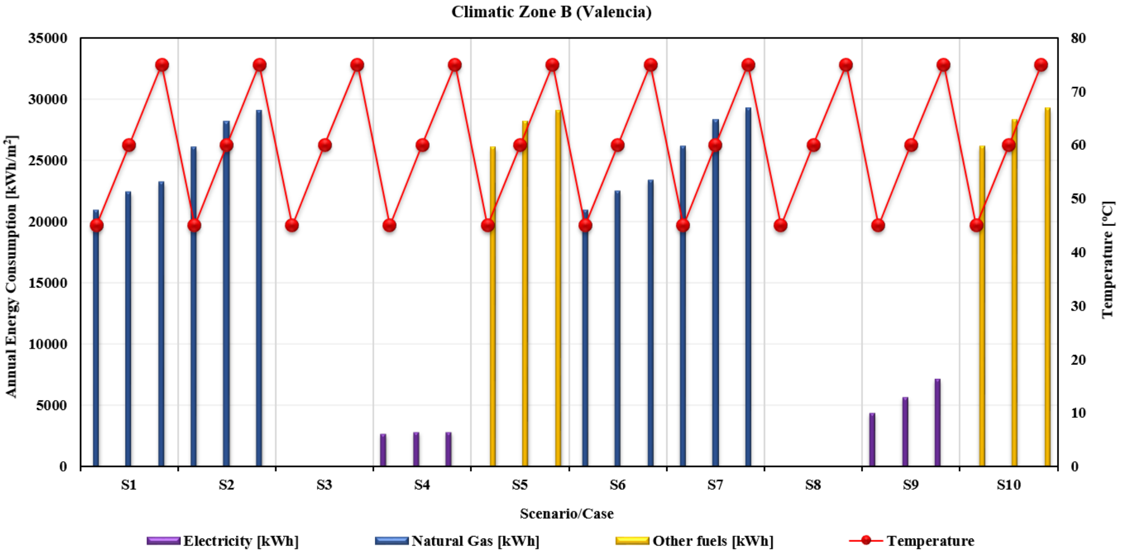


Figure 5.3: Annual energy consumption for climatic zone B (Valencia)

Figure 5.4 (graph) represent annual energy consumption for the different scenario of climatic zone D (Madrid). The summers in Madrid are relatively brief, hot, and dry with usually clear skies, while the winters are quite cold and partially overcast.

Figure 5.5 (graph) represent annual energy consumption for the different scenario of Climatic zone E (Burgos). The winters in Burgos are lengthy, extremely cold, windy, and partially overcast, while the summers are short, warm, and dry with largely clear skies. The summers are also usually clear.

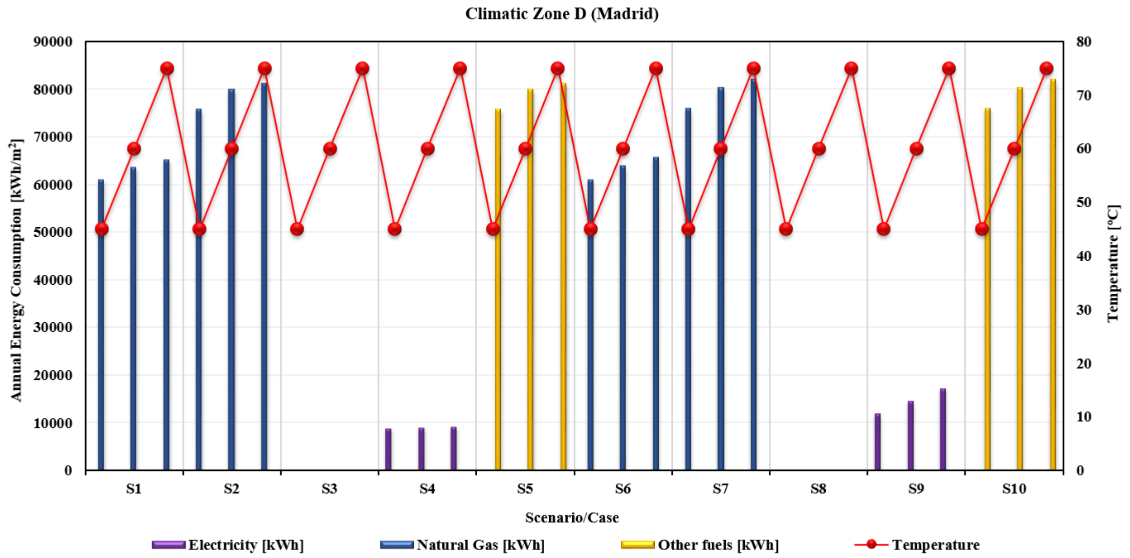


Figure 5.4: Annual energy consumption for climatic zone D (Madrid)

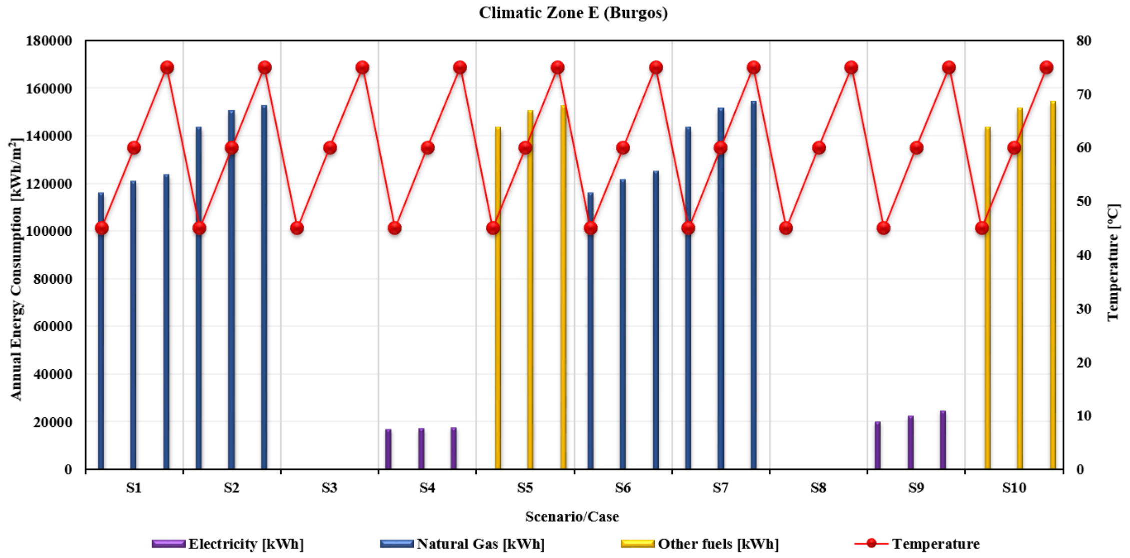


Figure 5.5: Annual energy consumption for climatic zone E (Burgos)

5.2 Discussion

Depending on the weather patterns, the use of energy in buildings may contribute to anywhere from 25 % to 40 % of total energy use in Europe. The majority of this energy usage is attributable to the provision of space heating and domestic hot water (DHW). Natural gas is one of the fuels that is used most often in the creation of heat in these appliances. If the operating parameters are such that the water vapor in the exhaust gases may condense, then condensing boilers have the potential to achieve an energy performance that is more than 100 percent above the lower heating value. As a consequence of this, it is required to optimize the operating settings of condensing boilers to reduce fuel consumption while still meeting the requirements for water heating.

However, Table 5.2 and Table 5.3 comprise between the energy consumption changes with different climatic zones where T represents Temperatures (°C), and S represents different Scenarios (S1-S10). Specifically, Table 5.2 comprise electricity and gas consumption and Table 5.3 comprise other fuels of 5 different climatic zones. Due to the different climatic zone, for Almeria (climatic zone A), the temperature seldom falls below 5.6 °C or rises over 35 °C during the course of a year, however, it regularly ranges between 8.3 °C to 30.6 °C. For Valencia (climatic zone B), the average temperature throughout the year ranges from 6.1 °C to 30 °C, seldom falling below 1.7 °C or rising over 33 °C. For Bilbao (climatic zone C), the temperature seldom falls below 1.11 °C or rises over 29 °C during a year, though, it frequently ranges from 5 °C to 24.4 °C. For Madrid (climatic zone D), the temperature seldom drops below -5.0 °C or climbs over 37.22 °C throughout a year, although it regularly ranges from 0.56 °C to 33.33 °C. For Burgos (climatic zone E), the average temperature throughout the year ranges from 6.1 °C to 30 °C, seldom falling below 1.7 °C or rising over 33 °C. However, the year ranges winter temperatures are reducing from climatic zone A to climatic zone E respectively. From the Table 5.2 and Table 5.3 it can be seen that, due to climate change, the use of energy for heating energy (annual energy consumption) is increasing. It can therefore be said that, the energy changes (Table 5.2 and Table 5.3) are due to the growing need for adequate thermal comfort in the case building. The potential effects of climatic zone changes on the heating load are the main parameters that determine the power consumption of the case building.

Table 5.2: Annual energy consumption for different scenarios (for 5 climatic zones)

S	T (°C)	Annual Energy Consumption (kWh/m^2)									
		Electricity (kWh/m^2)					Natural Gas (kWh/m^2)				
		A	B	C	D	E	A	B	C	D	E
S1	45	1.37	4.6	14.45	13.43	25.51	116069.05	20945.44	65681.68	60933.88	0
	60	1.51	4.86	14.90	13.84	26.21	120988.71	22414.71	68534.61	63559.36	0
	75	1.59	4.99	15.08	14.01	26.48	123807.83	23225.5	70108.78	65054.3	0
S2	45	1.37	4.58	14.38	13.36	25.37	143483.45	26092.92	81507.16	75743.52	0
	60	1.51	4.84	14.82	13.77	26.07	150587.67	28187.73	85884.39	79928.01	0

	75	1.58	4.96	15.00	13.93	26.34	152449.51	29018.6	87192.25	81180.49	0
S3	45	0	0	0	0	0	0	0	0	0	0
	60	0	0	0	0	0	0	0	0	0	0
	75	0	0	0	0	0	0	0	0	0	0
S4	45	1679.85	2736.09	8473.9	8863.21	17162.57	0	0	0	0	0
	60	1690.08	2824.58	8754.97	9114.77	17451.19	0	0	0	0	0
	75	1693.33	2873.47	8884.08	9235.16	17599.32	0	0	0	0	0
S5	45	1.37	4.58	14.38	13.36	25.37	0	0	0	0	81507.16
	60	1.51	4.84	14.82	13.77	26.07	0	0	0	0	85884.39
	75	1.58	4.96	15	13.93	26.34	0	0	0	0	87192.25
S6	45	1.37	4.61	14.48	13.44	25.52	116158.65	20970.55	65802.48	60986.06	0
	60	1.51	4.88	14.99	13.9	26.35	121654.87	22510.07	68971.26	63856.58	0
	75	1.59	5.01	15.23	14.12	26.76	125150.68	23390.92	70870.9	65616.93	0
S7	45	1.36	4.58	14.4	13.37	25.39	143625.98	26128.5	81664.74	75815.52	0
	60	1.51	4.86	14.91	13.83	26.21	151481.66	28293.86	86445.91	80303.42	0
	75	1.58	4.99	15.15	14.05	26.61	154182.84	29217.42	88167.52	81914.16	0
S8	45	0	0	0	0	0	0	0	0	0	0
	60	0	0	0	0	0	0	0	0	0	0
	75	0	0	0	0	0	0	0	0	0	0
S9	45	2924.51	4373.88	11985.03	12077.27	20215.15	0	0	0	0	0
	60	3744.71	5685.63	15041.46	14650	22499.39	0	0	0	0	0
	75	4689.84	7141.13	17993.54	17202.73	24707.92	0	0	0	0	0
S10	45	1.36	4.58	14.4	13.37	25.39	0	0	0	0	81664.74
	60	1.51	4.86	14.91	13.83	26.21	0	0	0	0	86445.91
	75	1.58	4.99	15.15	14.05	26.61	0	0	0	0	88167.52

Table 5.3: Annual energy consumption for different scenarios (for 5 climatic zones)

S	**T (°C)**	**Climatic Zones**				
		A	**B**	**C**	**D**	**E**
		Other Fuels (kWh/m²)				
S1	45	0	0	0	0	0
	60	0	0	0	0	0

	75	0	0	0	0	0
S2	45	0	0	0	0	0
	60	0	0	0	0	0
	75	0	0	0	0	0
S3	45	0	0	0	0	0
	60	0	0	0	0	0
	75	0	0	0	0	0
S4	45	0	0	0	0	0
	60	0	0	0	0	0
	75	0	0	0	0	0
S5	45	7827.93	26092.92	81507.16	75743.52	143483.45
	60	8852.64	28187.73	85884.39	79928.01	150587.67
	75	9300.97	29018.6	87192.25	81180.49	152449.51
S6	45	0	0	0	0	0
	60	0	0	0	0	0
	75	0	0	0	0	0
S7	45	0	0	0	0	0
	60	0	0	0	0	0
	75	0	0	0	0	0
S8	45	0	0	0	0	0
	60	0	0	0	0	0
	75	0	0	0	0	0
S9	45	0	0	0	0	0
	60	0	0	0	0	0
	75	0	0	0	0	0
S10	45	7821.17	26128.5	81664.74	75815.52	143625.98
	60	8865.19	28293.86	86445.91	80303.42	151481.66
	75	9339.47	29217.42	88167.52	81914.16	154182.84

In light of the findings, it is important to point out that the Technical Building Code of Spain does not establish any specifications for residential buildings concerning the amount of electricity that buildings consume on their own, even though this has a significant potential to result in optimal cases. However, in this study using the eppy scripting tool (Python language) in designing an HVAC system (active solution) for a heating system, the Design of the exit temperature (°C) of heating sizing is always kept equal to the set point manager temperature, and Loop design temperature difference (deltaC) is kept at 10 °C. The results of this study were obtained by doing a total of 150 simulations based on 10 different HVAC scenarios depending on the 5 climatic zones of Spain. In the case of HVAC designs, the amount of energy consumption (electricity, natural gas, and other fuels) varies proportionally with the temperature change. From the graphs discussed above, it can be seen that the use of the eppy scripting tool has also changed the energy consumption of the heating system based on the change of temperatures (set point manager) as well as the climatic zone and the scenario. Needless to say, using this method can quickly and accurately design a large building in a very short time. In addition to that, adopting this strategy makes it simple to create almost zero-energy structures.

6 Conclusion and Future Work

In conclusion, this work has a wide variety of distinctive qualities. The core aspect of this master thesis is to develop a technique for determining the operation that makes the most efficient use of various HVAC system setups for a variety of climatic situations and building types **(GO1)**. This study also plays a significant part in the large-scale deployment of nZEBs. In buildings, the purpose of HVAC systems is to give a certain level of thermal comfort; nevertheless, this often means high consumption of energy and significant installation costs. In buildings, energy is ultimately expended on heating and cooling the home environment, regardless of the season. Energy efficiency in HVAC systems has a significant impact on a building's overall energy usage. The proposed approach is based on the optimization of HVAC solutions through massive building energy simulations using DesignBuilder (DB) **(GO2)** and eppy scripting tools for EnergyPlus (E+) **(SO3,** and **SO4)**. The results map the best HVAC practices for different countries and the effects of different constraints, as well as the impact of specific costs and performance parameters **(GO3)**.

The DesignBuilder (DB) software has been used to design the reference building that is located near Bilbao (climatic zone C) and the HVAC system design for the reference building **(GO2)**. Then, the DB file (.dsb) of the reference building was exported to the EnergyPlus (E +) file (.idf) format which made it possible to edit or modify using eppy scripting in Python language (PyCharm software) **(SO4)**. For getting a better active solution with the help of the eppy scripting tool, the set-point manager temperature (heating only) has been changed to achieve the aim of this study **(SO5)**. Also, in the heating loop, the sizing of the "Design of the exit temperature (°C)" keeps the same as the set-point manager temperature, and the "Loop design temperature difference (deltaC)" has kept at 10 °C. However, the 30 different possible alternatives are identified for each location from the combination of the 10 distinct ESS scenarios (S1-S10) over the reference building **(SO2)**. A total of 150 simulation results were obtained based on the calibration of set-point manager temperatures (45 °C, 60 °C, and 75 °C) for five distinct climate regions of Spain.

The outcomes of the simulations are represented through graphs for five different climatic zones focused on the variation in annual energy consumption (electricity, natural gas, and other fuels) in kWh/m^2 after calibrating the set point manager (heating) temperature using eppy scripting. As in commercial buildings, about half of the energy used is devoted to maintaining a comfortable temperature, and energy consumption change as the temperature changes. Therefore, according to the goal of this work, the method of this study will be able to find the most cost-effective solution to meet the demand for major energy costs for the buildings **(SO1)**.

Moreover, during the tenure of this master thesis, by using the eppy script, it will be very easy to modify or edit different parameters for a building, and with this, it is possible to achieve: the best design for a building, the HVAC solution, reduce emissions, and reduce energy costs. Despite that, this study can be viewed from many perspectives. This study does not consider the need for cooling which is one of the limitations of the work, thus it can only be used for residential structures with thermal heating loads (such as space heating and domestic hot water (DHW)). Moreover, this study considered a set of alternative scenarios for the Energy Supply System (ESS) by keeping the Energy Saving Measure (ESM) unchanged. So, in future works, a cooling system can be taken into consideration. In addition, there is an implicit need for optimizing building design that combines passive elements or ESM, active systems or ESS, and on-site or nearby Renewable Energy Sources (RES) to meet a certain level of primary energy consumption at minimum cost. Finally, compared to the previous highly efficient static system investigated in this work, the proposed system has the potential to significantly reduce the annual building electricity and natural gas consumption which will help to reach the goal of achieving nZEBs.

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Appendix

Python script (eppy)

```
#%%

import sys

pathnameto_eppy =  "C:/Users/1076399/PycharmProjects/pythonProject/venv/Lib/site-packages/eppy"


sys.path.append(pathnameto_eppy)
from eppy.modeleditor import IDF

iddfile = "C:/Users/1076399/PycharmProjects/pythonProject/venv/Lib/site-packages/eppy/resources/iddfiles/Energy+V8_9_0.idd"

IDF.setiddname(iddfile)
import os
files=os.listdir("C:/Users/1076399/Documents/Mohammad/IDF files")
weather=os.listdir("C:/Users/1076399/Documents/Ane/weather")
epw_files = [_ for _ in weather if _[-4:] == ".epw"]
casos=[i.replace('.idf','') for i in files]
city=[i.replace('.epw','') for i in epw_files]


temp_boiler=[45,60,75]
```

```
for caso in casos:
    fname1 = f"C:/Users/1076399/Documents/Mohammad/IDF files/{caso}.idf"
    idf = IDF(fname1)

    setpoint_manager = idf.idfobjects['SETPOINTMANAGER:SCHEDULED']
    schedule = idf.idfobjects['SCHEDULE:COMPACT']
    design_loop = idf.idfobjects['SIZING:PLANT']

    for i in setpoint_manager:
        if i.Name == "Setpoint SueloRadiante":
            boiler = [i.Schedule_Name]

        if i.Name == "Circuito de AC auxiliar Control de Consigna":
            boiler = [i.Schedule_Name]

        if i.Name == "Circuito de Agua Caliente Control de Consigna":
            boiler = [i.Schedule_Name]

    for j in temp_boiler:
        for k in schedule:
            if k.Name == boiler[0]:
                k.Field_4 = j  # new temperature for boiler

        for k in design_loop:
            if k.Plant_or_Condenser_Loop_Name=="Circuito de calefaccion":
                k.Design_Loop_Exit_Temperature=j
            if k.Plant_or_Condenser_Loop_Name=="Circuito de AC auxiliar":
                k.Design_Loop_Exit_Temperature=j
            if k.Plant_or_Condenser_Loop_Name=="Circuito de Agua Caliente":
                k.Design_Loop_Exit_Temperature=j

        for l in range(len(epw_files)):
            os.chdir("C:/Users/1076399/Documents/Mohammad/output idf")
            idf.saveas(f"{caso}.{j}.{city[l]}.idf")
```

```
idf.epw=f"C:/Users/1076399/Documents/Ane/weather/{epw_files[l]}"
print(f"{caso}.{j}.{city[l]}")
idf.run(
    output_directory="C:/Users/1076399/Documents/Mohammad/simulations",
    output_prefix=f"{caso}.{j}.{city[l]}",
    )
```