ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

EFFECTIVENESS OF INTERVENTIONS ON ENERGY EFFICIENCY BY CONSIDERING HOURLY STATISTICAL ANALYSIS OF BUILDING ENVELOPE RETROFITTING

M.Sc. THESIS

Mahdiyeh ZAFARANCHI

Energy Science and Technology Division

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ISTANBUL TEKNİK ÜNİVERSİTESİ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

BİNA KABUĞUNDA YAPILACAK İYİLEŞTİRMELERİN ENERJİ VERİMLİLİĞİNE ETKİSİNİN SAATLİK İSTATİSTİKSEL ANALİZLERLE İNCELENMESİ

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Mahdiyeh Zafaranchi, a M.Sc. student of İTU Graduate School student ID 301181053, successfully defended the thesis/dissertation entitled "EFFECTIVENESS OF INTERVENTIONS ON ENERGY AND COST TO CONVERT EFFICIENT BUILDING BY CONSIDERING HOURLY STATISTICAL ANALYSIS OF BUILDING ENVELOPE RETROFITTING", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor :	**Prof. Dr. Hatice SÖZER** Istanbul Technical University	....
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To my family,

FOREWORD

Special thanks to Prof. Dr. Hatice SÖZER, who has been guiding me and provided patient advice every step of the research process. Moreover, I could not have achieved my current level of success without the encouragement of my parents, who supported me with love and understanding. Thank you all for your unwavering support.

January 2022 | Mahdiyeh Zafaranchi (Architecture Engineer)

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ABBREVIATIONS

AI	: Artificial Intelligence
ANN	: Artificial Neural Network
CDF	: Cumulative Distribution Function
CE	: Cost of Electric Consumption
CFL	: Compact Fluorescent Lamps
CG	: Cost of Gas Consumption
CO_2	: Carbon Dioxide
COP	: Coefficient Of Performance
CS	: Cooling System Setpoint
CT	: Total Cost of Energy Consumption
DOE	: Department of Energy
DX	: Direct Expansion
Ed	: Energy Demand
EIFS	: Exterior Insulation Finishing System
EPS	: Expanded Polystyrene Insulation
Es	: Energy Supply
GHG	: Greenhouse Gas
HVAC	: Heating, Ventilation, and Air Conditioning
IQR	: Isinter Quartile Range
LED	: Light Emitting Diodes
NA	: Not Applicable
PE	: Primary Energy
SVR	: Support Vector Regression
TC	: Based Model Cooling System Setpoint
TE	: Total Electric Consumption
TG	: Total Gas Consumption
TURKSTAT	: Turkish Statistical Institute
VRF	: Variable Refrigerant Flow

SYMBOLS

M	: Median Amount
N, n	: Number
Q_P	: Power of Each Panel
Q_T	: Total Installation Power
Q1	: First Quarter
Q3	: Third Quarter
R	: Thermal Resistance
U	: Final Thermal Transmittance
a	: Improvement Rate of Each Intervention
b	: Base Mode Energy Consumption
c	: Base Mode Spending Cost
d	: Material Thickness
f(x)	: Envelope Intervention Parameters
i	: Intervention Energy Consumption
j	: Intervention Spending Cost
r	: Coefficient of Correlation
s	: Standard Deviation
x, y	: Influence Rate
$\bar{x}$	: Mean
λ	: Thermal Performance of the Material
$	: Dollar

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EFFECTIVENESS OF INTERVENTIONS ON ENERGY AND COST TO CONVERT EFFICIENT BUILDING BY CONSIDERING HOURLY STATISTICAL ANALYSIS OF BUILDING ENVELOPE RETROFITTING

SUMMARY

The amount of energy consumption of buildings has obtained international concern so the concept of efficient energy building becomes a target for building designers. There are various definitions and evaluation methods for efficient buildings. However, detailed research about the critical parameters that have a major effect through the operational time to reduce the energy consumption is not emphasized as this research represents. This study identifies the effect of applicable interventions on energy consumption parameters with their sensitivity to each other to reach efficient energy building. Relatedly, the cost of energy reduction is also determined. In the next step, hourly investigation assesses to further improve building envelop.

Energy performance analysis combined with the white-box and statistic methods is exploited in the study. An educational-office building in the Mediterranean climate simulated by e-Quest to estimate electric and gas consumption; Results indicated the main energy consumption of the building is relative to electric consumption. In the following steps, sensitivity analysis was performed for cost and energy consumption for eight scenarios that include thermal performance of walls, roof, windows, assign shading devices, replacing lamps, dimming sensors, solar systems, and heat pumps.

After analyzing each scenario an envelope retrofitting scenario was suggested by a compound of passive strategies (thermal performance of walls, roof, windows, assign shading devices), which saved gas consumption by approximately 82% and electric consumption by about 2%. A compound of active strategies (replacing lamps, dimming sensors, solar systems, and heat pumps), which cover gas and electric demand.

In the second step, as a state of the art of this study, the hourly investigations of passive strategies were performed to demonstrate the side effects, which limited the rate of improvements in the envelope retrofitting scenario. Hourly negative effects had been presented. Dependency analysis of consumer parameters proved that the main object should be hourly consumption of the cooling system because of trapping heat inside the building, which causes undesirable influence during the transition months. Consequently, energy consumption of cooling system decreased by 41.44% which was 16.16% in envelope retrofitting scenario. Thus, the hourly investigation leads to increase energy performance more than traditional methods.

BİNA KABUĞUNDA YAPILACAK İYİLEŞTİRMELERİN ENERJİ VERİMLİLİĞİNE ETKİSİNİN SAATLİK İSTATİSTİKSEL ANALİZLERLE İNCELENMESİ

ÖZET

Binaların enerji tüketim miktarı uluslararası bir ilgi uyandırmış ve enerji verimli bina konsepti bina tasarımcıları için bir hedef haline gelmiştir. Verimli binalar için çeşitli tanımlar ve değerlendirme yöntemleri vardır. Çalışmalar farklı iklim koşullarında farklı bina türlerinin enerji tüketimini tahmin etmek için çeşitli yöntemler uygulamıştır; üstelik bazıları farklı yöntemlerden yararlanan verimli senaryolar önermektedir. Ancak herbir senaryonun enerji tüketim parametreleri üzerindeki etkisi ve senaryoların kendi aralarındaki farklılıkları halen tartışmalıdır. Ayrıca, bu çalışmaların çoğu, bina enerji performansının sonuçlarını aylık, yıllık veya mevsimsel olarak araştırmakta ve geleneksel çalışmalarda saatlik inceleme göz ardı edilmektedir. Aslında, enerji tüketiminin saatlik olarak belirlenmesi, bina enerji performansını daha da iyileştirecektir. Bu nedenle, genel verimliliği artırmak için, bu çalışmada ifade edildiği gibi uygulanabilir stratejilerin saatlik etkisinin analiz edilmesi değerlidir.

Akdeniz ikliminde yer alan bir bina örnek çalışma birimi olarak seçilmiştir. Bir binanın enerji tüketimini tahmin etmek, iklim durumu, konum, malzemelerin ısıl iletkenliği, mekanik sistemler, elektrik sistemleri, iç yük, Bina kabuğu özellikleri, sistem değişkenleri, çalışma programı, binanın işlevi gibi çeşitli etkili parametreler nedeniyle son derece karmaşıktır. Bahsedilen parametrelerin tümü, alan soğutma ve ısıtma, havalandırma fanları, pompalar ve yardımcılar, ekipman kullanımı, ortam ışıkları gibi bir binanın enerji tüketim parametreleri üzerinde büyük etkilere sahiptir.

Bu çalışmada, Akdeniz ikliminde yer alan, mevcut bir eğitim-ofis binası araştırılmış ve aktif ve pasif stratejilerle enerji verimli bir binaya dönüştürülmüştür. Bina simülasyonu, yıllık elektrik ve gaz tüketimini hesaplamak için e-Quest programında gerçekleştirilmiştir. eOUEST yazılımı, bir binanın enerji performansını tahmin etmek için bir araç olarak kullanılmaktır. eOUEST, bir yıl boyunca (8760 saat) bina enerji tüketimini saat saat hesaplamak için belirli bir konum için saatlik hava durumu verilerini kullanmıştır. Programın girdi bilgileri; bina sakinleri, aydınlatma ekipmanı, termostat ayarı, gölgeleme cihazları pencereler, bina kütlesinin saatlik planlanmasını; ayrıca, ısıtma ve soğutma sistemlerine dinamik tepkiler gibi bina özellikleri, ve doğal aydınlatmanın termal ve aydınlatma talebi üzerindeki etkisini değerlendirmek için dinamik aydınlatma modeli de içermektedir. Parametrelerin enerji tüketimi ayrıca genel elektrik ve gaz, bina özelliklerine dayalı olarak eQUEST tarafından hesaplanmıştır.

İkinci adımda, binanın enerji karakteristiğini belirlemek ve enerji tüketim parametreleri ve genel enerji performansı üzerindeki etki oranını göstermek için sekiz senaryo önerilmiştir. Sekiz senaryo duvarların, çatının, pencerelerin termal performansını, gölgeleme cihazlarını atamayı, lambaları değiştirmeyi, karartma sensörlerini, güneş enerjisi sistemlerini ve ısı pompalarını içermektedir. Ek olarak, maliyet ve enerji kullanımı için duyarlılık analizleri önerilmiştir. Bir sonraki adımda

önerilen senaryolar aktif stratejiler ve pasif stratejiler olmak üzere iki kısma ayrılmıştır.

Aktif stratejiler uygulamak, mevcut binaları sıfır tüketimli binalara dönüştürmenin pratik yollarıdır. Bina sektöründe enerji tüketimini azaltmaya yönelik farklı stratejiler arasında sıfır tüketimli binalar, enerji kullanımını azaltmanın yanı sıra yenilenebilir kaynaklardan yararlanma konusunda gelecek vadeden bir potansiyele sahiptir. Elektrik tüketimini azaltmak için lambaların değiştirilmesi ve karartma sensörleri ile aydınlatma sistemlerinin yükseltilmesi; elektrik tüketimini karşılamak için güneş enerjisi sisteminin uygulanması; gaz tüketimini karşılamak için ısı pompası sisteminin kullanılması sıfır tüketimli binaya ulaşılması amacıyla değerlendirilmiştir.

Etkili aktif stratejilerden biri güneş panelleri sistemi; gaz tüketiminde küçük bir yan etki ortaya çıkmasına rağmen, elektrik tüketiminde %84,75 tasarrufu ve dolayısıyla %78,53 birincil enerji tasarrufu sağlayarak. Bu sistem %13 verimliliğe sahip 152 adet PV panel, 4 adet pill ve bir adet konvertörden oluşan sistemdir. İkinci adımda, CFL lambaların LED lambalarla değiştirilmesi elektrik kullanımı %9,58 oranında düşürmüş, ardından karartma sensörlerinin eklenmesiyle %15,50'ye yükselmişken, gaz tüketiminde yan etki %12,39'a gösterdi; ancak elektrik, gaz kullanımından daha etkilidir, dolayısıyla birincil enerji iyileştirme oranı %13,47 olmuştur. Üçüncü adımda, 4.5 COP değerine sahip toprak kaynaklı ısı pompası ele alındı; bu, alanı ısıtmak için 2370 Kwh/yıl elektrik enerjisi kullanmak anlamına gelir (temel modelde gazdan alan ısıtma için gerekli enerji 10.670.72 kWh/yıl). Isı pompası binanın gaz tüketimini ortadan kaldırmış ve birincil enerjiyi %5,48 oranında iyileştirmiştir. Bu nedenle, her türlü bina ve iklim için geçerli olabilecek söz konusu yöntemlerle sıfır enerji tüketimi sağlanabilir.

Maliyet-fayda oranı en yüksekten en düşüğe doğru %84,33 güneş enerjisi sistemi, aydınlatma sistemlerini %15,37 iyileştirme ve ısı pompası %1,71 tasarruf olabilir. Böylece, nihai senaryoda, 5.545$ elektrik maliyeti ve 27$ gaz maliyeti olmak üzere toplamda 5572$ tasarruf sağlanabilecektir.

Pasif stratejiler: Pasif stratejilerin gaz tüketi üzerinde daha fazla etkisi vardır. Daha detaylı olarak, dış duvar yalıtımı gaz kullanımını yaklaşık %46 yani 4.873,77 kWh/yıl, çatı yalıtımı %5 yani 550,97 kWh/yıl, pencerelerin değiştirilmesi %31 yani 3.299,98 kWh/yıl ve gölge cihazları %42 oranında tasarruf sağlamıştır, yani 4.437,10 kWh/yıl gaz tüketimini azaltılmıştır. Iyileşmiş bina kabuğu olarak adlandırılan son pasif senaryo, yalnızca genel tüketimler için değil, aynı zamanda her bir tüketici parametresi için de pozitif performans gösterdi. Bina kabuğu iyileştirilmesi, gaz tüketimini 8,768,69 kWh/yıl miktara tekabül eden %82, elektrik tüketimini ise 940,00 kWh/yıl büyüklüğüne denk gelen %2 oranında azalttı. Sonuç olarak, birincil enerjide %7,5 yani 10.987,09 kWh/yıl iyileşme ortaya çıkmıştır. Nihai maliyet faydası yılda 111,22 $ civarındadır. Pasif stratejilerin lektrik tüketiminden ziyade gaz tüketimi üzerinde daha yüksek bir etkiye sahiptir. Daha detaylı bakılırsa, dış duvar yalıtımı gaz kullanımını yaklaşık %46 yani 4.873,77 kWh/yıl, çatı yalıtımı %5 yani 550,97 kWh/yıl, pencerelerin değiştirilmesi %31 yani 3.299,98 kWh/yıl ve gölge aletleri %42 oranında tasarruf sağlamıştır. yani 4.437,10 kWh/yıl gaz tüketimini azaltır.

Pasif stratejiler, tüm bina kabuğunu ve binanın enerji performansını güçlendirir. Nihai pasif senaryo, güçlendirmenin enerji performans etkisini, aylık bazda değerlendirmede görülemeyecek olumsuz etkileri ortadan kaldırmak için saatlik bazda tahsis etmiştir. Buna göre, Iyileşmiş bina kabuğunu enerji performansı saatlik olarak incelenmiştir. Bu çalışmanın yeniliği saatlik araştırıp yan etkileri bulmak ve bunları tam olarak iyileştirmektir. Bu yöntem, enerji performansını geleneksel yöntemlere göre daha iyi hale getirmek için daha akıllı çözümler keşfedebilir. Tüm yıla uyan kalıcı bir stratejiye güvenmek yerine mevcut duruma göre belirli çözümler uygulayarak pasif stratejilerin performansını artırmaktadır. Ek olarak, iyileşmiş bina kabuğunu senaryosunun saatlik analizi, binanın artan enerji performansı için faydalı olacak bina davranışının daha doğru bir şekilde belirlenmesine yardımcı olur. Bu çalışmanın ana katkıları aşağıdaki noktalarda özetlenebilir:

Yıllık sonuçlar olumlu olmasına rağmen, araştırmanın saatlik etkisi bazı olumsuz etkiler bildirmiştir. Bu nedenle, verimliliği artırmak için bina enerji tüketiminin daha hassas bir şekilde araştırılması gerekli olabilmektedir. Iyileşmiş bina kabuğunu senaryosunun saatlik araştırması, soğutma alanı ve havalandırma fanları için bazı saatlerde yan etkiler göstermiştir. Bağımlılık oranı ve veri dağılımlarına bağlı olarak saatlik soğutma performansı iyileştirilmelidir. Havalandırma fanlarının gaz tüketimi ile ters bir ilişkisi vardır; bu durumda havalandırma fanlarının daha düşük yan etkisi (%-4,23) ile gaz tüketiminden (%85,31) daha yüksek bir fayda oranı elde etmek en uygun seçenektir. Ayrıca, izolasyon geçiş aylarında binanin ısısini icinde haps ediyor bu nedana soğutma sisteminin saatlik incelenmesi yan etkileri gosterdi. Ancak geçiş aylarında soğutma sisteminin 1.5C noktasının değiştirilmesi, sorunu %78'e kadar telafi edebilir, bu da konfor bölgesinde negatif saatlerin 112'den 24 saate düşmesi anlamına gelmektedir. Bu nedenle soğutma sisteminin enerji tüketimini iyileştirme oranı %16,16'dan %41,44'e yükselmiştir.

Bu çalışmanın yeniliği, enerji tüketimi parametrelerinin sadece toplam enerji tüketimi üzerindeki etkilerini değil, aynı zamanda birbirleri üzerindeki etkilerini de belirleyerek, enerji tüketimi parametrelerinin duyarlılık analizindeki boşlukları doldurmaktır. Bazı müdahaleler birbirini olumsuz etkilerken genel tüketim üzerinde olumlu bir etkiye sahip olabilmektedir. Bu kritik etkinin ayrıntılı olarak belirlenmesi, yalnızca enerji performansını daha da iyileştirmekle kalmayıp aynı zamanda müdahalelerin karar verme sürecini de etkileyebilmektedir.

Çalışma benzer binalara uygulanabilir. Gelecekteki çalışmalarda daha fazla strateji entegre edilmesi ve duyarlılık analizi yapılması önerilmektedir. Sonuçlara göre, gelecekteki çalışmalarda farklı işlevlere ve iklimlere sahip çeşitli binalara stratejiler uygulanırsa, büyük miktarda enerji ve maliyet tasarrufu sağlanacak; dolayısıyla çevre için olumlu bir etki ortaya çıkmış olacaktır.

1. INTRODUCTION

The global concern in energy and environmental pollutants in form of climate change, waste accumulation, ozone layer depletion, etc. is rise day by day [1]. The construction sector is one of the main energy consumption and natural resources sectors; consequently, it rise the rate of pollution globally. Buildings are responsible for 40% of world energy consumption [2] and 23% of greenhouse gas emissions[3, 4] which are growing day by day. Even a simple retrofitting of buildings with the energy efficiency concern would represent an enormous effect. Predicting a detailed energy usage profile of buildings is fundamental to develop strategies[5, 6]. Thus, the improved energy consumption of buildings and accurate prediction of consumption become critical.

In Turkey, based on TURKSTAT information the total number of buildings was 4.3 million in 1984 which reached 7.8 million in 2000 which means growing by 78%. Moreover, construction permits issued declared a 56% increase in land covered by residential, commercial, and public buildings that mean covering 1,524 million m2 between 2000 until 2008, and the total number of buildings raised by 7%. In 2009, the CO_2 emission of the building sector in Turkey was 53.4 million tonnes and the sector's energy consumption was 29.5 million tonnes; it is estimated to be double in 2020 by 47.5 million tonnes [7]. Rely on sources, CO_2 emissions of Turkey grew by 125% during the 25years (1990-2014) also primary energy demand increase annually by 6% [8]. In 2015, Based on the submitted Intended Nationally Determined Contribution to the United Nations Framework Convention on Climate Change, Turkey has to reduce 21% of GHG emission by 2030 compared to 2010 [9]. Therefore, green buildings should be promoted to achieve energy efficiency and energy conservation.

This study aims to investigate of energy consumption of an educational building in the Mediterranean climate to convert an existing building into an efficient energy building by saving energy and renewable sources. Subsequent purposes are analyzing the effect of each strategy on energy consumption and cost.

Variety methods have been used to estimate the energy consumption of buildings that can be separated into three types: the white-box method, the grey-box method, and the artificial intelligence(AI) data-driven method[10]. The white-box method calculates energy usage of different kinds of buildings based on thermodynamic rules by simulation software such as EnergyPlus, eQUEST, and Ecotect[11]. The prediction is done by building design details and location information such as weather data, thermal performance of the envelope, mechanical and electrical information also HVAC systems, in other words, variety-specific information should be available to simulate accurety[12]. There are varieties of studies that applied these methods. In a study, eOuest software was used to forecast hourly and seasonally energy consumption of a city by prototypical buildings and geospatial data. The main purpose was estimating anthropogenic sensible and latent waste heat emissions to declare urban heat island and air quality[13]. Another study proved that zero energy building can be achievable by improving envelop, air-conditioning, and lighting systems also integrating photovoltaic panels. The study has done on a school in Hong Kong that has a hot and humid climate[14]. The research compared the accuracy of three methods of building energy estimation with a case study; there were eQUEST, IESVE Revit Plug-in, and Green Building Studio. Final results declare eQUEST has 98% accuracy in electricity and 97% in gas usage, IESVE has 72% in electricity and 99.8% in gas consumption, Green Building Studio has 96% exactness in both gas and electric usage [15]. In another study, a Gas driven absorption heat pump is used for heating and cooling loads of library buildings. Simulation energy of building confirmed eQUEST average electricity consumption 1.5% below and gas consumption 7% less than actual usage annually; however, the accuracy could be increased by on-site weather measurement, collection of hourly energy consumption, and occupancy data[16]. A study showed hourly solar radiation has a high impact on the energy simulation of building in comparison with monthly or yearly statistical indices. This method has been done by eQUEST[17]. A study investigated the effect of climate change on the energy consumption of residential and office buildings by using hourly future climate data (during 2040–2069 years) and EnergyPlus software. According to the study, energy use will be decreased generally; to be more specific the energy use of lighting and fans will slightly decrease in the future. Although electricity consumption for cooling is going to grow, the energy use for heating is going to decline in the future. Decreasing primer energy used for buildings inclination of electricity is more than natural gas or oil[18]. Based on other researche energy consumption will be an increase in the future due to cooling systems[19-23]. In 2100, it is predicted worldwide heating energy demand will be decreased by 34% whereas cooling demand increase by 72% by considering climate change[24].

The grey-box method is a hybrid model that employed simple physical models to simulate building energy systems. A dominant model for building energy consumption is determining resistors and capabilities thermal network model; the measured data is analyzed in statistical ways instead of using physical characteristics of a building. Hence, grey-box models require a long time and are more costly in comparison to white-box models. In research, hourly and daily measured data of a house were analyzed by simple and multiple linear regression and quadratic regression. This model declared one of the important factors of estimation is time. Multiple linear regression models and root mean square error confirmed by outdoor temperature and solar radiation. Moreover, the main emphasis was on the performance of HVAC systems due to the high consume energy[25]. Hourly energy consumption of four houses measured and climate data taken from the close climate station to estimate heating energy usage hourly by regression models. A simple linear model predicts with the difference of indoor and outdoor weekly average temperature by 2.5% error and multiple linear regression with global horizontal solar radiation by 9.0% error due to sample size, observation period, and the model used[26]. Actual daily temperature and energy consumption from bills were used as data to detect the potential of energy saving of residential buildings. The focus was on the hot-water heater, programmable thermostat, envelope, HVAC systems. Gas and electricity usage was the base of two regression also variables defined by the difference between the outdoor temperature and the balance point temperature[27]. Regression model developed to calculate monthly heating demand of single-family residences. The aim of the study investigating the shape of a building, thermal performance of the envelope, window to floor area ratio, building time constant, and climate. The hourly simulation was done byTRNSYS software[28]. A linear regression model estimated natural gas and electricity consumption of single dwellings based on building type, construction year, and occupant number. [29].

The AI data-driven method predict the energy consumption of building independent of interior and individual parameters of buildings; this method solves nonlinear problems. The two effect model of this method is an artificial neural network(ANN) and support vector regression(SVR)[30, 31]. In this method, the first step is adjusting the data such as eliminating outliers, predicting missed values, and normalizing the data than analyzing data. Data are divided for accurate prediction of building energy consumption under diverse operation conditions and times [32]. In research, the one-year energy consumption of campus buildings is separated based on semesters and an independent prediction model is suggested for each semester to improve the forecast[33]. In another study, a decision tree model according to the building cooling load and time variables is recommended to present an operation building pattern[34]. A paper proposed indirect optimal pattern recognition by connotative incidence relation between fluctuation features and influencing factors of a building. Model is simulated a day-ahead via fuzzy C-means clustering and nonlinear regression. The model was applied to an office building to recognize unsteady HVAC energy usage templates [35]. Moreover, building energy control has been gradually changed from the experimental type into the elaborative intelligent control[36]. Hence, separate building patterns are more valuable than designing a model for each of them to improve the prediction of energy consumption. A study presented the influence of solar radiation on gas demand prediction that is used for heating the space of a house. Hourly data recorded then converted to the daily data and prediction problems solved based on the past, current, and future values. linear and nonlinear regression compared with each other and confirmed whereas nonlinear models have small training errors, unable to increase generalization on test data because errors are slightly higher than linear models[37].

One of the practical policies in this field is modification existing buildings to efficient buildings. Energy efficiency refers to the adoption of specific methods that supply or reduce the energy consumption of a building without big changes. The very low or almost zero energy requirement is significantly covered by renewable energy sources, produced on-site. In the following step, the possible potential of energy saving and producer sources was evaluated.

Artificial light sources play an indispensable role in the daily life of any human being. Electrical light sources are responsible for energy consumption of around 16% to 20% of worldwide electricity production[38]. Therefore, there is high saving potential. Nowadays, there are many opportunities to improve existing lighting systems of buildings; not only for efficiency but also for higher quality. Common energy-efficient lightbulbs are halogen incandescent, compact fluorescent lamps (CFLs), and light-emitting diodes (LEDs).

The average heat flow of Turkey was estimated at 74 W/m^2, which determined geothermal energy of Turkey is higher than the world average due to volcanic mountains [39]. Thus, geothermal energy can be a reasonable and environment-friendly source to supply energy. A heat pump transfers thermal energy from a cooler space to a warmer space (refrigeration cycle); the system utilizes to warm and sometimes to cool buildings. Common devices are air source heat pumps, ground-source heat pumps, water source heat pumps, and exhaust air heat pumps. Heat pumps are also often used in local heating systems.

Another abundant and reliable resource of renewable energy is solar power. Solar potential is excessive in Turkey due to the specific location[40] especially in the southern part of Turkey (approximately 1,330 kW/m2per year)[41]. It is worthwhile to mention each gigawatt solar power installation would reduce 100 million dollars on the gas bill[42]. The main challenge of solar panels can be the cost of panels and the rate of efficiency (the percentage of getting sunlight that is converted into electricity). The rate of the most efficient solar panels on the market is around 23% and the average installed panels are between 15%-18%. The standard panel on average has 300w power that depends on the brand has 16%-20% efficiency and the price depend on manufacturers is between $200-$400 [43]. Based on sources external factors such as irradiance (W/m2), shading, panel orientation, temperature, location (latitude), time of year, dust, and dirt could decrease the rate of efficiency in the real world [44].

Important criteria to install a solar system is the weight and size of panels; in other words, a roof should support panels. The average size of panels for a rooftop is mostly around 165cm*99cm with 4-5 cm depth and 18.14kg although it is variable from brand to brand; moreover, the standard size of cells is 15.6cm*15.6cm. Solar panels usually are made up of 60 solar cells for rooftop panels. The commercial solar panels are bigger in comparison to the mentioned common type that has 183cm long with 72-98 or more cells. The weight of panels is usually between 15kg - 23kg[45].

One of the obligations of solar panels should be storing systems to save the excess electricity of solar panels and used it when required. However, one of the challenges about batteries is a lifetime which is usually between 5-15 years; therefore, it is necessary to replace batteries to match with the lifespan of solar power system which is about 20-30 years. Effective factors to prolong solar battery's life could be battery type (lead-acid, lithium-ion, or saltwater), battery usage means avoiding overcharge or discharge completely (most batteries are deep-cycle batteries that means able to discharge until 80% before recharging), battery temperature (should be in optimum temperature to maximize life and efficiency so installation place can be important), battery warranty which depends on manufactures, and proper maintenance[46].

Mentioned tactics could be considered as main parameters in modifying a conventional type building to an approximately independent or zero consumption building. Moreover, it is worthwhile to mention active strategies have a high potential to cover the energy requirement of educational buildings by saving and producing energy.

In this study, a combination of methods was applied. In the first part, the white-box method was used for simulation and sensitivity analysis; in the next part, statistic methods were supported to identify and adjust data for achieving the final object which was raising the building energy performance.

1.1 Background and Related Work

A motivating study was developed for an office building in New York. It used hourly meteorological and energy consumption data to predict the energy performance of the building's accuracy and get optimal energy results. In the first step categorize and classify energy usage was utilized based on the energy consumption pattern by decision tree; in the next step, the ensemble learning method was applied to predict consumption of each pattern, and finally, the accuracy of the model was proven. Results showed that time of day, month, and type of days (weekday, weekend) are effective factors for an office building in New York City. Time and day types impact building occupancy because energy consumption decreased after work hours and during off days; furthermore, the effect of the month appeared due to climate features[47].

In another study, the effectiveness of heat pumps for space heating in cities was shown by regression analysis. Different heating methods such as heat pumps, gas heating, electrical heater, and the combination were compared. Surveys and actual consumptions were used as data. The least-squares method was used in the multivariable linear regression. Size of house, number of occupants and stories, years from construction, the orientation of the house, heating temperature, and a dummy variable that indicated heat pump dependency was relative variables[48]. A regression model predicted electricity consumption of housing units by 9 variables that were the number of occupants, house status (owned or rented), the annual average number of vacation weeks, type of fuel for the pool, space and domestic hot water heating, air conditioning system, and the number of air variables per hour at 50 Pa. The survey, site audits, and audit of smart meters information were employed to collect data[49]. The purpose of the study was energy saving by natural ventilation and adaptive setpoint temperature. Based on the study adjusting cooling degree is more effective than heating systems[50].

Additionally, a study work on the impact of occupancy characteristics of end-user groups on energy prediction performance. It is possible to determine the personalized energy patterns (e.g., load shape, the amount of energy use) for end-user groups to reduce energy consumption without sacrificing comfort. The object was obtained by a data mining-based prediction model[51].

Research retrofit buildings envelop in a hot climate by passive methods to decline energy usage. The strategies focus on radiative, convective, and thermal performance through walls, windows, roofs, also natural ventilation techniques that lead to economic growth and energy efficiency. The research demonstrated building orientation, thermal insulation could save energy more than 20% especially in residential buildings; moreover, appropriate glazing type and orientation could save higher than 55% energy in high rise buildings like office buildings; besides, excessive light levels, glare, and natural ventilation could reduce energy consumption more than 30% in villas and 79% in a high rise office building[52].

The research investigated the influence of passive strategies on thermal comfort and energy consumption of an office building in coastal tropical climates. The results confirmed phase change materials and thermal insulation could raise the comfort rate by 3% and decline cooling energy by about 12% by addition natural ventilation the comfort rate increase. Furthermore, combing external shading with thermal insulation reduced cooling energy demand by approximately 19%. In the next step, photovoltaic panels suggestion supplied 43–79% of the total energy consumption of the building[53].

An investigation indicated the effect of thermal wall isolation and shading tools on cooling energy performance of different sides of a residential chamber in summer by considering inside and outside temperature as well as humidity. The case study was located in a hot climate. According to the results wall thermal insulation prevented wasting energy by 23.5% in summer and created a comfortable situation. The impact of insolation from high to low can be in order like west, north, east, south so uniform thermal insulation applicant is not cost-effective. Moreover, south face shading tools for windows have a good effect on energy performance[54]. The other research proves exterior wall insulation has a better influence on cooling and heating energy consumption in comparison with only interior insulation[55]. Wall insulation in residential villas in Dubai could save 30% of energy consumption[56]. Interior setpoint temperature is one of the important factors for cooling load. There is an opposite relationship; by increasing the temperature setpoint the cooling load decrease also if the interior setpoint temperature increases beyond a set value (25.72◦C), the annual cooling load becomes negative[57].

An educational building retrofit by passive strategies to reduce average energy consumption by 33% and increase comfort in a hot arid climate. Suggested strategies were wall insulation, window types, infiltration, solar shading devices. The study investigated each strategy separately and showed shading devices decreased energy usage by 23%, windows by 8%, airtightness by 2%, and wall insolation by no effect[58]. Another study reached 83% electric reduction in a residential building in Cairo by envelope improvement, efficient solar protection, high thermal inertia, and hybrid ventilation also domestic water heating, photovoltaic panels, and solar thermal air conditioning[59]. Envelop retrofitting decreased energy consumption by 28%[1]. Improvement educational building was done in a hot climate to increase energy performance and mitigate CO_2 emission. Retrofitting glazing, insulation, and green roof application could reduce energy usage by 15% in comparison with the base model[61].

The research investigated internal air convective heat balance and their interrelations with different boundary conditions for a residential and office building. A multi-step parametric method was used to simulate and compare the effect of retrofit solutions.

The main concentration was thermal transmission through envelope on cooling energy demand. The results verified a limited impact of the entire envelope on cooling performance especially opaque parts due to the prevalence of heat loss. However, sensitivity analysis showed transparent parts had a high effect regarding the size and the thermal and solar parameters[62]. Walls insulation increases energy consumption during the transitional seasons[63].

According to the renewable technology agents, expanding renewable generation will be increased because of declining investment cost and capability of cooperation in network reserve supply which leads to a high utilization factor[64].

Based on research, 49% of the energy consumed was allocated for air-conditioning and 15% of energy was relative to lighting systems in a library. The effect of four factors which were lighting power density, indoor personnel density, summer indoor design temperature, and summer air supply temperature, on energy consumption was investigated. The study showed lighting power density has a direct and highest impact on building energy consumption[65].

An investigation was done on intelligent lighting control systems. Lights turned off when people left the place. The suitable design provides desired illumination and uniformity light which pleasure users [66].

User perceptions were examined by design characteristics of light switches that encourage users to turn off lights when leaving the space. the result of the study proved the importance of affordances in reducing energy use from lighting [67]. This study could show the potential saving in lighting systems.

The purpose of the study was maximum electric production by focusing on the inclination and direction of solar panels, module type, and installation distance to the module length ratio. Panels could supply 1-5% of a typical office building in Korea in electricity. the highest electric energy is produced during April and May, however, energy production significantly declines in July because of weather conditions. Furthermore, the southeast and southwest panels have high production. According to the study harvesting the highest energy depends on the surface area, inclination, distance/length ratio with panels, panel types and their efficiency, panels cost, restrictions related to building functionality, and aerostatic of a building [68].

An interesting study assesses the feasibility of using an off-grid solar-based hybrid system on a household scale for electric production. In economically optimal status, 70% of required energy can be provided by solar cells, and it was calculated about 2 years payback time so the remaining time, that was 23 years, would be profitable [69].

A study suggested that achieving zero energy building is possible by adjusting energy-consuming parameters such as space heating/cooling, lighting, ventilation, and so on; besides, based on climate conditions, requirement energy supplied with renewable sources. This study used a combination of passive and active strategies to decline energy consumption and introduce zero energy building[70].

An interesting study retrofitted an existing building with active and passive strategies. The study assessed the rate of improvement for each strategy and cost-effectivity. One of the most cost-effective active strategies is the efficient lighting system, and efficient air conditioning systems were in the second step. lighting pies was The most cost-effective passive strategy; lighting controls were in the second step. Moreover, the payback time of passive strategies was longer than active strategies also passive design should apply on a larger scale to have significant energy improvements. Energy-saving of passive strategies was 5% whereas energy saving of active strategies was between 40%-45%. lighting retrofits improve energy performance by 12-17% and air-conditioning until 23-28% [71].

A paper investigated the feasibility of zero energy buildings. Energy consumption dropped 30% by passive strategies and energy demand of building meat by maximizing the use of solar energy as renewable energy[72].

The purpose of an interesting study was to upgrade existing buildings through the adoption and application of sustainable technologies; that include lighting and automation, heating, ventilation, and air conditioning (HAVC) systems and equipment, envelope, renewable energy, and passive technologies[73].

Research optimize the energy consumption of heating, cooling, and lighting system. Suggestion strategies were insulation of walls and ceiling, using green roof, double glazing UPVC windows, light intensity sensor, and variable refrigerant flow (VRF) system that saving amount of energy was calculated around 21.1, 7.9, 26.41, 27.3, and 72.3 %, respectively. Moreover, integrating five scenarios represented 86.9% energy reduction [74].

A paper assessed air source heat pump with 2.36 COP to heat the water of residential buildings. Results indicated a 50% reduced energy consumption by renewable sources [75].

According to a study net-zero energy building was separated into three categories that involve energy infrastructure connections, renewable energy sources, and energy efficiency measures [76]. In addition, there are several types of definitions for zero energy buildings one of them declares zero energy building is energy self-sufficient and produces as much energy as it uses[77]. In this study, the main consideration is renewable energy sources and energy efficiency measures. The energy-efficient measurements include passive strategies and active strategies. However, based on the relative sources passive solutions such as daylighting and natural ventilation have application limitations since they are sensitive to climate and outdoor conditions [78-81].

Therefore, active strategies such as improved lighting systems can be a reliable method for existing buildings to reduce energy demand. This study integrated two types of renewable sources to supply the energy requirement of a building; also, artificial lighting is one of the main energy consumer parameters in buildings that have a high potential to decrease energy consumption easily. In this study, an exiting educational-office building transformed into an efficient building in Mediterranean climate by consuming zero energy during the lifetime of the building. The mentioned method can apply to any kind of building to reduce electric and gas consumption.

The above-mentioned studies have applied various methods to estimate the energy consumption of different building types in different climatic conditions; some also suggest efficient scenarios exploiting different methods. However, the effect of each scenario on energy consumption parameters and differences of scenarios with each other is still questionable. Besides, most of these studies explore the results of building energy performance on a monthly, annual or seasonal basis, and hourly investigation is ignored in customary studies. In fact, hourly determination of energy consumption will further improve building energy performance. Thus, to improve overall efficiency, it is worthwhile to analyze the hourly influence of applicable strategies as this study represents. A method was developed for investigating and predicting the building energy consumption more precisely to increase efficiency. Sensitivity analyses were executed for developed strategies that involve the thermal improvement of the building envelope including exterior walls, roof, windows, and shading devices. Results were investigated and compared with each other to select a suitable strategy. Afterward, the selected envelope intervention was explored for hourly investigation, and also the rate of dependency was declared for energy consumer factors. Although annual results were positive, investigation hourly influence declared negative impact in some hours, especially on cooling performance. Then, the hourly effect of envelope retrofitting on cooling performance was evaluated and improved.

The novelty of this study is filling gaps in sensitivity analysis of energy consumption parameters by not only identifying their effect on overall energy consumption but also identifying their effect on each other. Some interventions may have a positive effect on overall consumption while having a negative effect on each other. Identifying this critical effect in detail not only further improves the energy performance, but also may affect the decision-making of the interventions.

2. METHODOLOGY

2.1 Identifying the Building Specifications

A building was selected as a case study in the Mediterranean climate. Estimating the energy consumption of a building is extremely complicated due to various effective parameters such as climate condition, location, thermal performance of materials, mechanical systems, electrical systems, internal load, envelop specifications, system variables, operation schedule, function of the building. All of the mentioned parameters have a major influence on a building's energy consumption parameters that include space cooling and heating, ventilation fans, pumps and auxiliaries, equipment usage, area lights. In this study, an existing educational-office building in the Mediterranean climate was investigated and transformed into an energy-efficient building by active and passive strategies.

2.2 Analyzing the Energy Performance Through Energy Simulation

2.2.1 Evaluation of energy consumption

eOUEST software is used as a tool to estimate energy performance of a building. eOUEST is combination of a building creation wizard, an energy efficiency measure wizard, and graphical reporting with a simulation "engine" as represented in Figure 2.1 [82]. eOUEST used hourly weather data for a specific location to calculate hour-by-hour building energy consumption during an entire year (8760 hours). Input information of the program include hourly scheduling of occupants, lighting equipment, thermostat setting, shading devices, fenestration, building mass; moreover, considering building features such as shading, dynamic responses to heating and cooling systems, also dynamic lighting model to assess the influence of natural lighting on thermal and lighting demand. The energy consumption of parameters also overall electric, and gas calculated by eQUEST based on the building specifications [83].

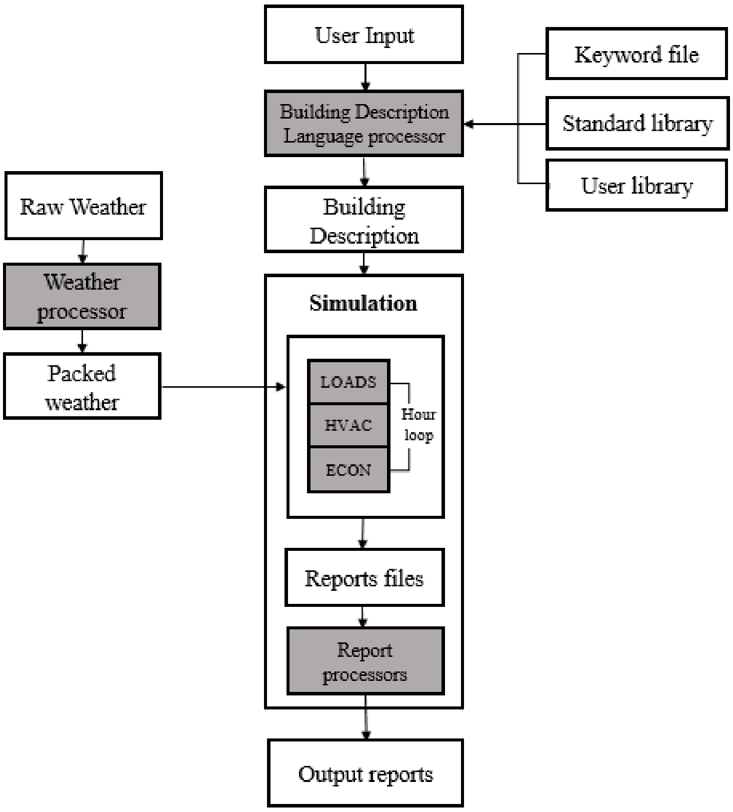


Figure 2.1: DOE-2.2 program flow (shaded boxes are programs) [82].

Additionally, primary energy consumptions are estimated by equation 1. The primer energy was calculated based on coefficient factors of Turkey, which is taken 2.36 for electricity as mentioned in Republic of Turkey Ministry of Energy and Natural Resources.

$$PE = (TE * 2.36) + TG \quad (2.1)$$

Where PE is primary energy [kWh], TE is total electric consumption [kWh], 2.36 is the coefficient of electricity production in Turkey, TG is total gas consumption [kWh].

Besides, the cost of bills was calculated by Equation 2.2. based on the Turkey price (Turkey's electric price is $95 per thousand kWh[84] and gas $26 per thousand m3[85]).

$$CE = TE * 0.095 \quad (2.2)$$

$$CG = TG * 0.0025$$

$$CT = CE + CG$$

Where CE is cost of electric consumption [$], 0.095 is cost of 1 Kwh electric consumption, CG is cost of gas consumption [$], 0.0025 is cost of 1 Kwh gas consumption, CT is total cost of energy consumption.

2.2.2 Sensitivity analysis of interventions

Four passive scenarios were developed that include thermal performance of walls, the thermal performance of roof, replacing windows, shading devices. Passive strategies have a considerable effect on space heating and cooling. Passive strategies lead to energy reduction and introduce energy-efficient building. Moreover, four active scenarios suggested include replacing lamps, adding light sensors, solar systems, and a soil source heat pump. Active strategies transform an existing building into a zero energy building. The main consideration is the utilization of renewable energy sources by considering energy efficiency measures. Also, artificial lighting that is the main energy consumer parameter in buildings is improved to obtain zero consumption building. Active strategies are suggested that decline the overall energy consumption to zero. The mentioned method can apply to any kind of building to reduce electric and gas consumption.

In the second step, sensitivity analysis was done to indicate the effect of each of them on the energy performance of consumer parameters and overall energy. The detailed analysis of energy consumption parameters leads to not only identifying their effect on overall energy consumption but also identifying their effect on each other. Some interventions may have a positive effect on overall consumption while having negative effects on each other. Identifying these critical effects in detail not only further improves the energy performance, but also affects the decision-making process of the interventions. The formulation of the impact of interventions on energy consumption parameters is calculated by using equation 2.3.

$$a = \frac{b - i}{b} .100 \qquad (2.3)$$

where a is the improvement rate of each intervention [%] in other words rate of saving, b is the energy consumption of each parameter for base model [Kwh], i is the energy consumption of each parameter for the intervention case [Kwh].

The formulation of cost sensitivity of each intervention is calculated using equation 2.4.

$$a = \frac{c - j}{c} .100 \qquad (2.4)$$

c is spending cost of base model [$], j is the cost of intervention cases [$].

The effect of each applied intervention on energy consumption was classified as high, medium, low, very low, no effect, and negative effect by utilizing a sensitivity analysis. Additionally mentioned scenarios compared with each other. In the third step, based on the second step two final scenarios were introduced as an envelope retrofitting and an active scenario. Zero energy consumption was accessible by combining active scenarios; however, the envelope retrofitting scenario required further investigation. The cost of energy reduction is also determined.

2.3 Hourly Statistical Analysis of Envelop Retrofitting

Hourly determination of energy consumption will further improve building energy performance. It is worthwhile to analyze the hourly influence of applicable strategies to improve overall efficiency. A method was developed for investigating and predicting the building energy consumption more precisely to increase efficiency. Therefore, hourly investigations were performed to demonstrate the side effects, which limited the rate of improvements in the envelope retrofitting scenario.

In the begging, the hourly energy consumption of envelope intervention was statistically identified by Rstudio. Side effects of the intervention were discovered by space cooling and ventilation fans. Data distribution and correlation analysis indicated that the improvement object should focus on the cooling system because of a positive high dependency on primary energy. The negative effect of ventilation fans was ignored because of the negative dependency on primary energy. The hourly investigations indicated hourly side effects because of trapping heat during transition months. In the last step, negative values of the cooling system were separated from positive effects also relative times, and the temperature was recognized.

$$f(x)\begin{cases} \text{Intervention} & x < 0 \;\; \begin{cases} \text{Intervention \& Improvement} & r > 0 \\ \emptyset & r \leq 0 \end{cases} \\ \emptyset & x \geq 0 \end{cases} \quad (2.5)$$

Where f(x) is envelope intervention parameters, x is influence rate [%], if the influence rate is negative, data will be identified and the distribution will be investigated otherwise it will be ignored (∅). In the next step, if the coefficient of correlation (r) with primary energy is positive, negative data will be investigated in terms of temperature and influence rate otherwise will be ignored. In the final step after the identification of negative hours, a suggestion will decrease negative influences that improve overall results.

According to the achimenes information, some pieces of advice were applied to the envelope intervention scenario to decrease side influences. Consequently, the final performance increased. Once and for all, a final step is suggested that decline the overall energy consumption. The schematic process is shown in Figure 2.2.

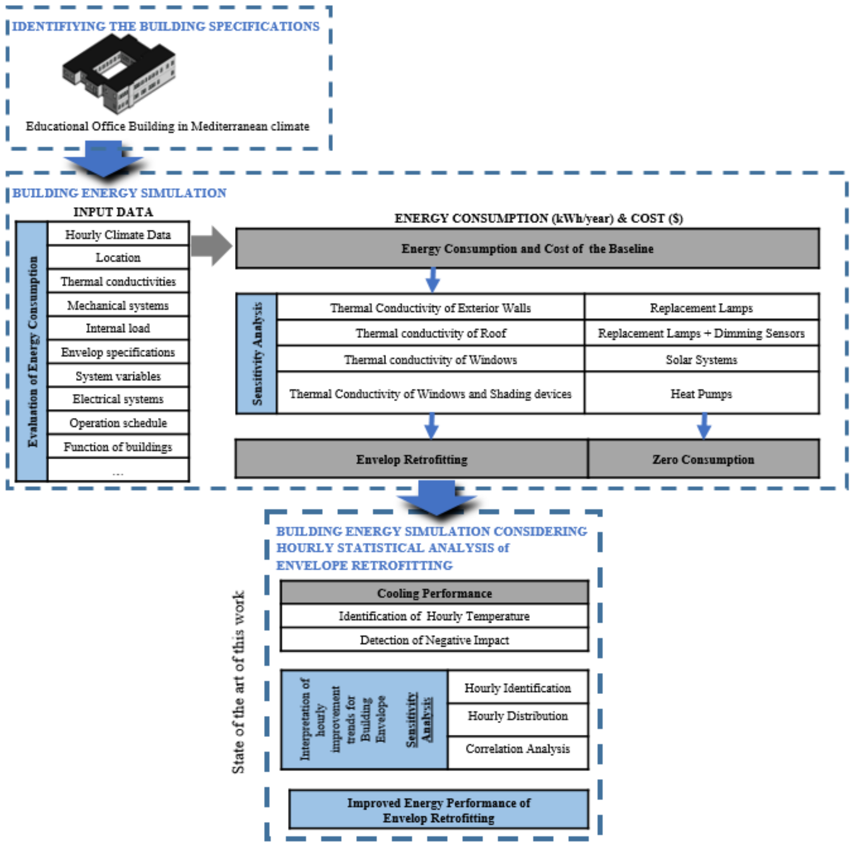


Figure 2.2: Methodology.

3. IDENTIFYING THE CASE STUDY SPECIFICATIONS

3.1 General Overview of Case Study

Energy Institution of Istanbul Technical University is selected as a case study in Maslak, Istanbul, Turkey as shown in Figure 3.1. The building is utilized as an education building that also has offices for faculties and administrators. An educational-office building is selected as a case study. Educational buildings have different energy profiles due to the operational time, multi-functioned spaces that include classes, meeting rooms, offices, laboratories, and so on; besides the number of users in educational buildings is fluctuated, also architectural design of these kinds of buildings required certain specifications such as the direction of windows in classes. The case study was built as a concrete block with a courtyard. The total retrofitting area is 465.8 m2 as represented in Figure 3.2. The building has a high energy consumption due to poor insulation. Therefore, some passive strategies were suggested for improvement to sustain its energy performance.

Figure 3.1: Location of Case Study[86].

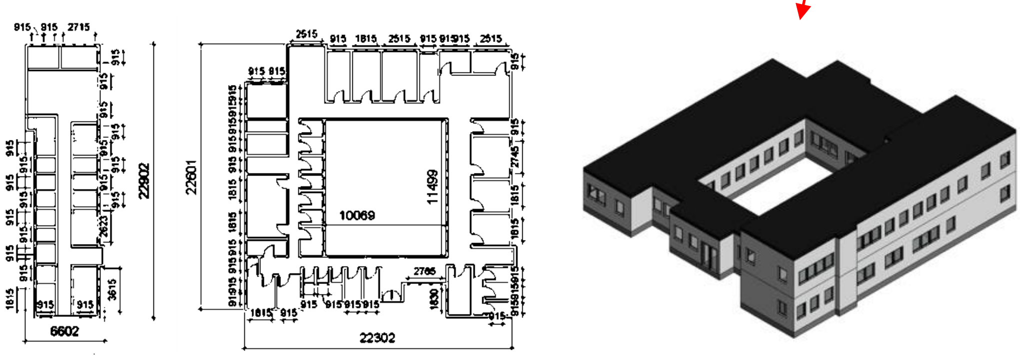


Figure 3.2: 3D Modeling and 2D Plane of Case Study.

3.2 Climate Condition of Case Study

According to the Köppen- Geiger Climate Classification, Istanbul has a “Mediterranean or Csa” climate which refers to dry-summer subtropical climates. Most of the Mediterranean region has relatively mild winters and very warm summers [87]. Overall climate charts are shown in Figure 3.3. The case building is located in the Sariyer district (41°06’28.8” N 29°01’50.5” E). Sariyer is 164m above sea level with warm and temperate also has rainfall winters. The average temperature of Sariyer is 14.9 °C | 58.8 °F and precipitation is around 676 mm | 26.6 inches annually [88]. More specific climate information of the case study is clarified in Table 3.1.

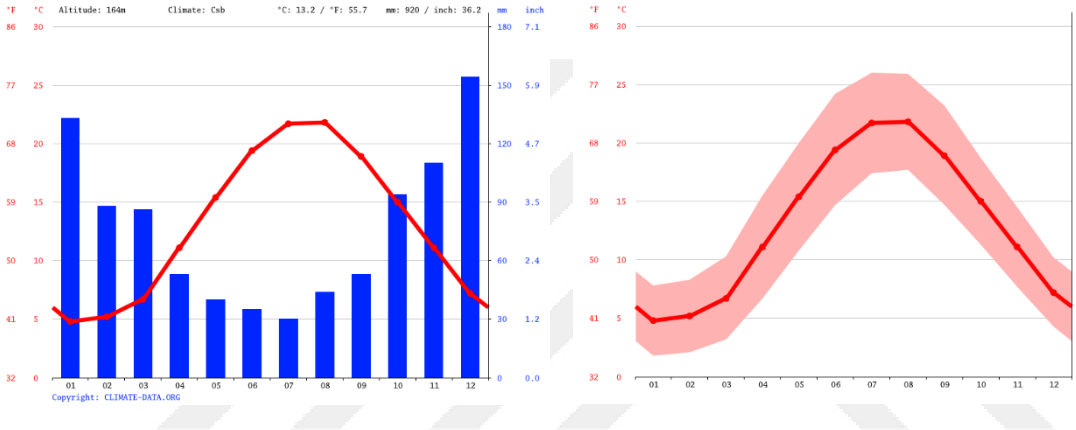


Figure 3.3: Monthly Sariyer Climate Graph and Sariyer Average Temperature[88].

Table 3.1: Sariyer Monthly Temperature and Precipitation.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg Temperature(C)	5.9	6.5	8.6	12.1	17.1	21.9	24.5	24.8	21.1	16.3	12.1	7.9
Min Temperature(C)	3.5	3.8	5.3	8.3	13.2	18	20.9	21.7	18.1	13.8	9.7	5.7
Max Temperature(C)	8.3	9.3	12	16.1	21.1	25.7	28.2	28.3	24.4	19.1	14.8	10.2
Precipitation/Rainfall (mm)	75	67	68	44	35	36	29	27	55	78	68	94

The monthly precipitation and temperature data for Sariyer are shown in Table 3.1. Minimum, maximum, and average temperature is given in Celsius unit and precipitation is given in mm unit. The driest month is August by about 27mm | 1.1 inches and the most precipitation in December by about 94mm | 3.7 inches. The warmest month has an average of between 21.7 to 28.3°C in August and the coldest average is between 3.5 to 8.3 °C in January [88].

3.3 Features of Case Study Before the Interventions

The total area is considered 465.8 m^2; the ground floor is 342.8 m^2 that includes 9% classroom, 53% offices, 37% corridors, 1% wet places also the first floor with 123 m2 consist of 65% offices and 35% corridors as represented clearly in Figure 3.4. Also, more specific information about existing spaces is mentioned in Table 3.2.

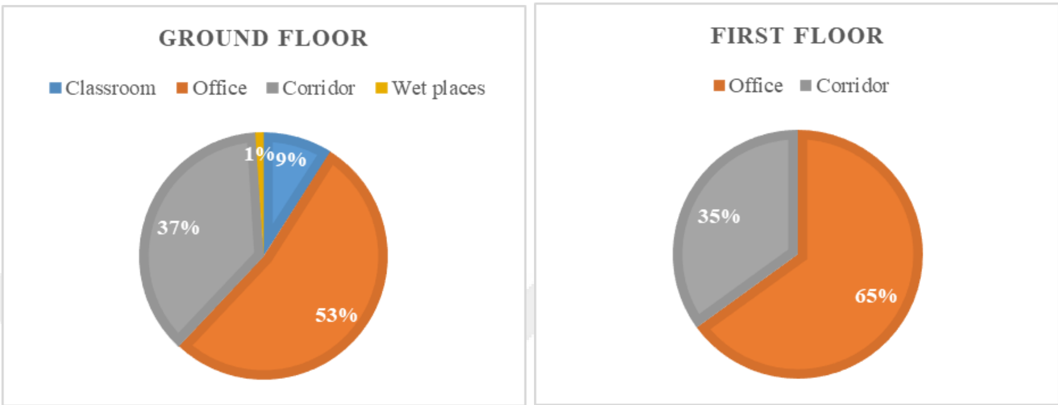


Figure 3.4: Representing the Functionality of Case Study.

Table 3.2: Specific Information about Existence Spaces.

Area Type	Percent area (%)	Design Max Occup (SF/person)	Design Ventilation (CFM/per)	Lighting (W/m^2)	Office Eq (W/ m^2)	Electric Load (W/m^2)	Electric Sensible (W/ m^2)
classroom	7	75	15	15.60	7.53	5.38	107.64
offices	56	200	20	16.03	41.86	8.07	107.64
Corridor	36	1000	50	6.13	0.00	0.00	107.64
wet places	1	200	15	12.80	0.00	10.76	107.64

The building has double glazed windows with 1.8 W/m^2K U-value and an aluminum frame also windows have light color curtains to protect from extrasolar radiation and heat gain. Windows are10cm sunk into the building shell. Ground floor windows are about 21.3% (floor to floor 21.3% floor to ceiling 25.5%) and the first floor is about 15.4% (floor to floor 15.4% floor to ceiling 20%). There is no other daylight control in the building.

The U-value of the building is adjusted based on TS 825 of 2013;[89] the overall U-value for walls is 0.57 W/m^2K and the roof is 0.38 W/m^2K. Material information is mentioned in Table 3.3.

Electric use of the building is relative to interior (ambient) light, office equipment, miscellaneous equipment, exterior lighting, pumps & Auxilience, ventilation fanes also DX coils for cooling of offices space. Gas consumption is used as energy for hot water coils to heat spaces. Moreover, three seasons are defined for the building (winter, summer, fall + spring) and break days are adjusted based on the academic calendar to adjust systems' operation time. The summary of information is mentioned in Table 3.4.

Table 3.3: Material Information of the Case Study.

Building Components	Material Name	Unit weight	Area	Volume	Mass	U values (W/m²K)
Windows	Glass	23.7 kN/m³	211 m²	1.23 m³	2982.84 kg	1.8
	Aluminum	26.6 kN/m³	331 m²	3.67 m³	9935.87 kg	
Wall	Paint	0.1 kN/m³	2356 m²	3.53 m³	35.9954 kg	
	Plaster	0.000077kN/m³	2356 m²	4.12 m³	0.0324 kg	0.57
	EPS	0.5 kN/m³	1178 m²	29.46 m³	1472.81 kg	
	Concrete Masonry Units	23.6 kN/m³	1178 m²	200.31 m³	482189.36 kg	
Roof	EIFS, Exterior Insulation	0.2 kN/m³	359 m²	8.97 m³	206.39 kg	
	Damp-proofing	22.8 kN/m³	718 m²	1.79 m³	4181.58 kg	0.38
	Concrete, Precast	23.6 kN/m³	8339 m²	461.00 m³	984903.37 kg	

Table 3.4: Summary Input data for Case Study.

Case Study Features	
Location	Sariyer, Istanbul, Turkey
Building Function	Office-School
Total Area	466m²
Building Operation Schedule	8 AM – 5 PM School in Session 9 AM – 4 PM Low use for Remaining Days
Window to Wall Ration	23%
Cooling System	DX coils for Offices
Heating System	Hot water coils
U-value of Windows	1.8 (W/m²K)
U-value of Walls	0.57 (W/m²K)
U-value of Roof	0.38 (W/m²K)

4. ANALYZING THE ENERGY PERFORMANCE THROUGH ENERGY SIMULATION

4.1 Evaluation of Energy Consumption of Case Study

The analysis is starting with the white box method as explained in the introduction part. The building is simulated by eQUEST [90] for 365 days and 8760 hours per year to calculate actual electric and gas consumption. The weather file of the model got from Green Building Studio in 2020.[91] All effective data including building geometry, weather condition, heating, ventilation, and air condition (HVAC) systems, interior load, operation schedule were used as input data for modeling the existing building. Finally, the energy consumption of the building was calculated for each parameter. The highest consumption was relative to miscellaneous equipment due to office equipment consumption (about 60% of the total area is office space), area light was in the second step (CFL lamps were considered for the whole building), in the next steps pumps & luciferase, space cooling that considered just first-floor office spaces, exterior equipment which includes exterior lights, and ventilation fans were in the last steps. Then total primer energy was calculated based on coefficient factors of Turkey, which is taken 2.36 for electricity and adding to gas consumption that is calculated by equation 3.1. The case study consumes 57,610 KWh electric, 10,670.72 KWh gas, and 146,630.32 KWh primary energy in a year. Table 3.5 is exhibited energy consumption of parameters, total energy, and primary energy annually. Moreover, the cost of energy was calculated based on the unit price of electricity and gas in Turkey. Based on the results annual total energy cost is 5,499.63$ that indicated in Table 3.6.

Table 4.1: Energy Consumption of Existing Model [Kwh].

Parameters	Space Cool	Vent. Fans	Pumps & Aux.	Ext. Usage	Misc. Equip	Area Lights	Total Electric	Total Gas (Heating)	Primary energy
Base Mod.	2,970.00	1,650.00	2,990.00	2,350.00	32,690.00	14,960.00	57,610.00	10,670.72	146,630.32

Table 4.2: Cost of Energy Consumption [$].

Yearly Bill Cost	Electric cost	Gas cost	Total cost
Base Model	5,472.95	26.68	5,499.63

4.2 Sensitivity analysis of Suggested Interventions

4.2.1 Thermal performance of exterior walls

Exterior walls of base model content concrete masonry units, Expanded Polystyrene Insulation (EPS), plaster, and paint which had 0.57 W/m^{2}K U-value. Thermal performance of suggested model is calculated by using equation 4.1.

$$R = \frac{d}{\lambda} \tag{4.1}$$

$$U = \frac{1}{R1 + R2}$$

Where R is thermal resistance, d is material thickness [m], λ is thermal performance of the material [W/K·m] (according to each material). Where U is final thermal transmittance [W/m²·K].

The thermal performance of walls was changed from 0.57 W/m^{2}K to 0.16 W/m^{2}K by adding 100mm polyurethane as shown in Figure 4.1 and Table 4.1.

100 mm polyurethane [92] (U-value = 0.225):

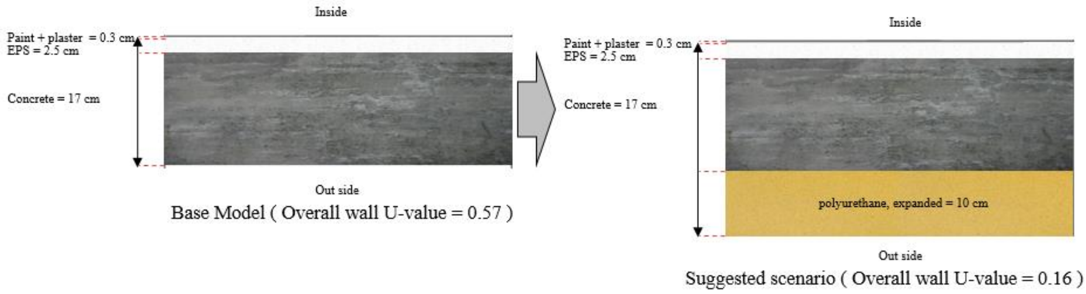


Figure 4.1: (a) Current External wall of the Case Study, (b) Estimated Retrofitted External wall of the Case Study.

Table 4.3: Suggested U-value of Exterior Walls [W/m^{2}K].

Scenarios	U-value of walls
Base model [89]	0.57
Base model + 100mm polyurethane	0.16

Based on eQUEST results, thermal insulation of walls had sharply decreased on space heating by 45.67% which draw 4873.77 kWh/year gain due to protecting inside heat during cold days of winter and had a positive effect on ventilation fans by 4.85% with an energy saving of 80 kWh/year. The thermal performance of walls did not affect pumps & Auxiliary, exterior usage, equipment usage, and area light; consequently, the electric and gas bills were lower than the base model in order 0.03% and 45.67% that meaning 14.08$ yearly (Table 4.3 and Figure 4.3). However, decreasing thermal performance led to harder thermal transfer through walls so the warm air was captured inside of the building; that caused a minor negative impact on electric consumption of space cooling by 2.02% (-60 Kwh/year) which was negligible by considering 4893.77 Kwh/year reduction of overall final energy consumption with 7.17%. Moreover, improving the thermal performance of walls shows a positive influence on primary energy by 3.36% that is 4920.97 Kwh/year as illustrated in Table 4.2 and Figure 4.2.

In the following steps, sensitivity analysis was done. Also, improve the rate of scenarios were arranged. A specific range of improvement; 40 until 100 percent a high effect, 10 until 40 percent a medium effect, 5 until 10 percent low effect, 0 until 5 percent showed a very low effect, zero no effect, and finally negative demonstrated side effect as mentioned in Table 4.4.

Table 4.4: Individual Effect of Exterior Wall Insulation on Energy-Consuming Parameters [%].

Energy consumption	Energy consumption of parameters compared with base							Total energy		Primary energy
	Space Cool	Vent. Fans	Pumps & Aux.	Ext. Usage	Misc. Equip	Area Lights	Space Heat	Electric consumption	Gas Consumption	
Thermal performance of Walls	-2.02	4.85	0.00	0.00	0.00	0.00	45.67	0.03	45.67	3.36

Table 4.5: Individual Effect of Exterior Wall Insulation on Cost [%].

Energy consumption parameters	Electric cost	Gas cost	Total cost
Thermal performance of Walls	0.03	45.67	1.93

Table 4.6: Rate of Effect.

Range of Effect	
40-100%	High
10 - 40%	Medium
5 – 10%	Low
0 – 5%	Very Low
0	No Effect
0%>	Negative

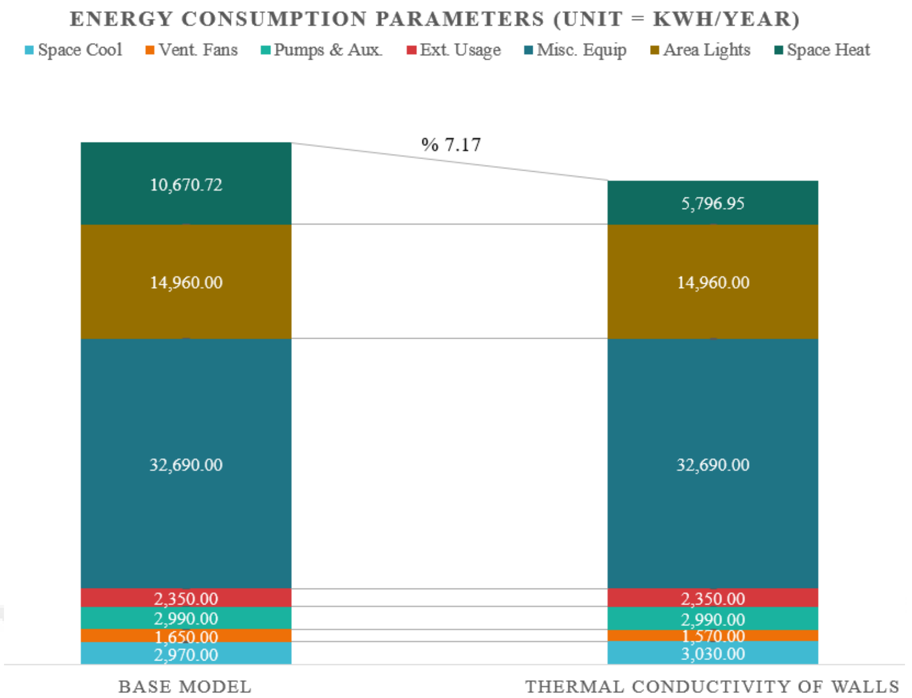


Figure 4.2: Exterior Wall Insulation Effect on Energy-Consuming Parameters.

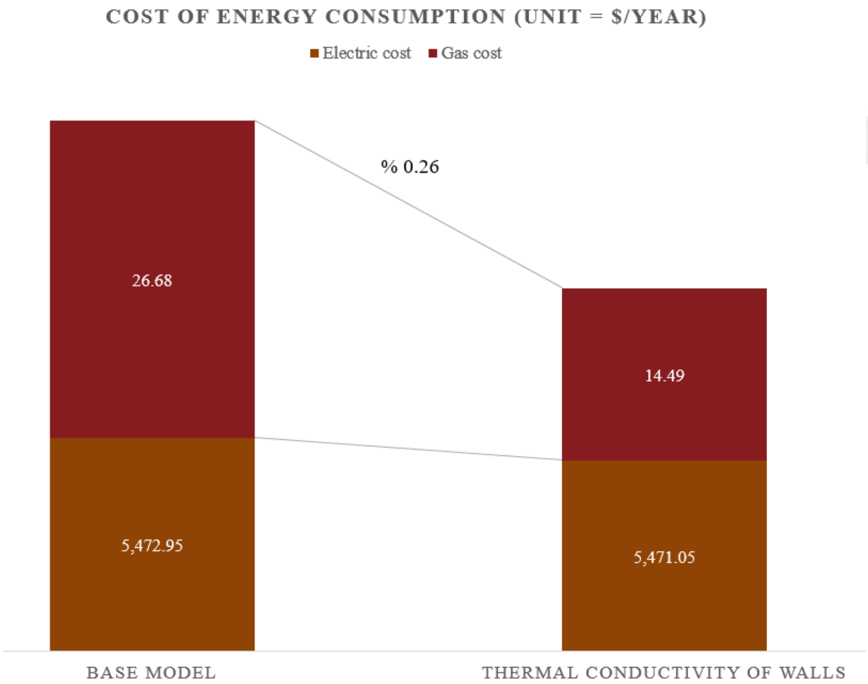


Figure 4.3: Exterior Wall Insulation Effect on Cost.

4.2.2 Thermal performance of roof

Materials of the base model were concrete, precast, damp-proofing, EIFS, exterior insulation with 0.38 W/m^{2}K thermal performance which decreased to 0.14 W/m^{2}K by adding 100mm polyurethane in this scenario. [92]. Thermal performance of roof is calculated by using equation 4.1. Table 4.5 represented used roof thermal performance.

Reducing thermal performance of roof had a benefit on space heating by 5.16% which led to 550.97kWh/year energy saving. This intervention had a slightly beneficial on space cooling and ventilation fans by 0.34%, 0.61% respectively which equals to 20kWh/year. Also no effect on pumps & Auxiliary, exterior usage, equipment usage, and area light; subsequently, electric and gas bills were decreased by 0.03% and 5.16% which brings 3.28$ gain (Table 4.7 and Figure 4.5). By preventing the heat lost through the roof the overall energy saving was calculated as 570.97 kWh/year which was 0.84% of total energy also 0.41% primary energy that is about 598.17 kWh/year. Table 4.6 and Figure 4.4 are shown the level of effect on energy consumption.

Table 4.7: Suggested U-value of Roof [W/m^{2}K].

Scenarios	U-value of Roof
Base model [89]	0.38
Base model + 100mm polyurethane	0.14

Table 4.8: Individual Effect of Roof Insulation on Energy-Consuming Parameters [%].

Energy consumption	Energy consumption of parameters compared with base							Total energy		Primary energy
	Space Cool	Vent. Fans	Pumps & Aux.	Ext. Usage	Misc. Equip	Area Lights	Space Heat	Electric consumption	Gas Consumption	
Thermal performance of Roof	0.34	0.61	0.00	0.00	0.00	0.00	5.16	0.03	5.16	0.41

Table 4.9: Individual Effect of Roof Insulation on Cost [%].

Energy consumption parameters	Electric cost	Gas cost	Total cost
Thermal performance of Roof	0.03	5.16	0.06

4.2.3 Thermal performance of windows

The base model had a 1.8W/m^{2}K U-value with aluminum frame windows; it was double and argon gas filled it. Another kind of window type was suggested for all windows of the building. The suggested model had double insulated glazing and argon filling in 22mm; the thermal performance of the suggested windows was 1.1 W/m^{2}K with wooden operable frames as shown in Table 4.8.

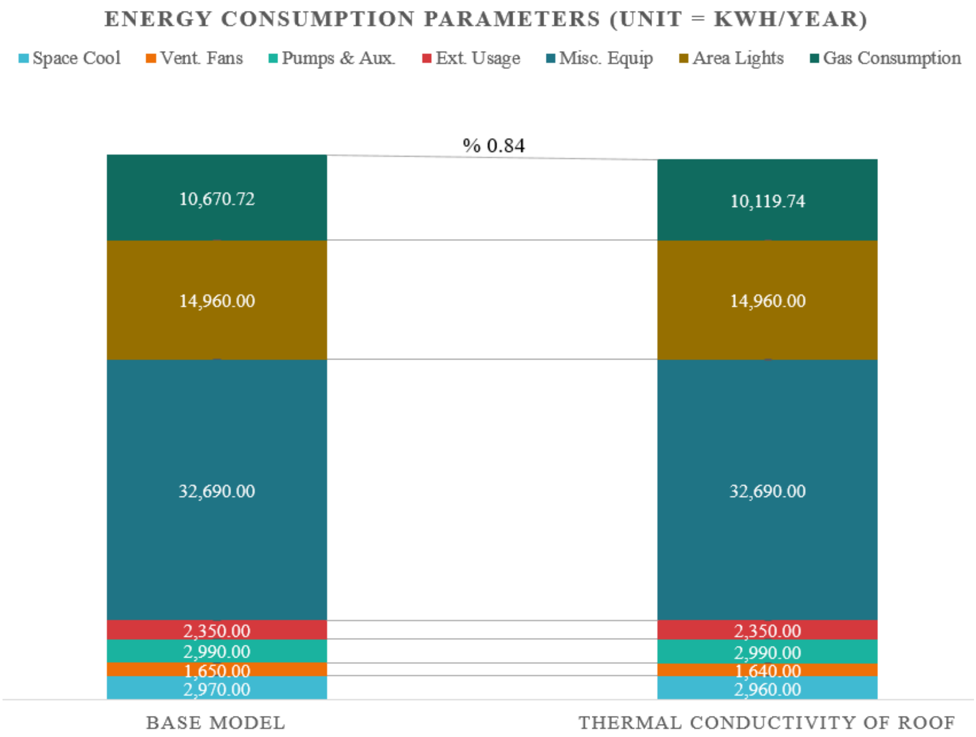


Figure 4.4: Roof Insulation Effect on Energy-Consuming Parameters.

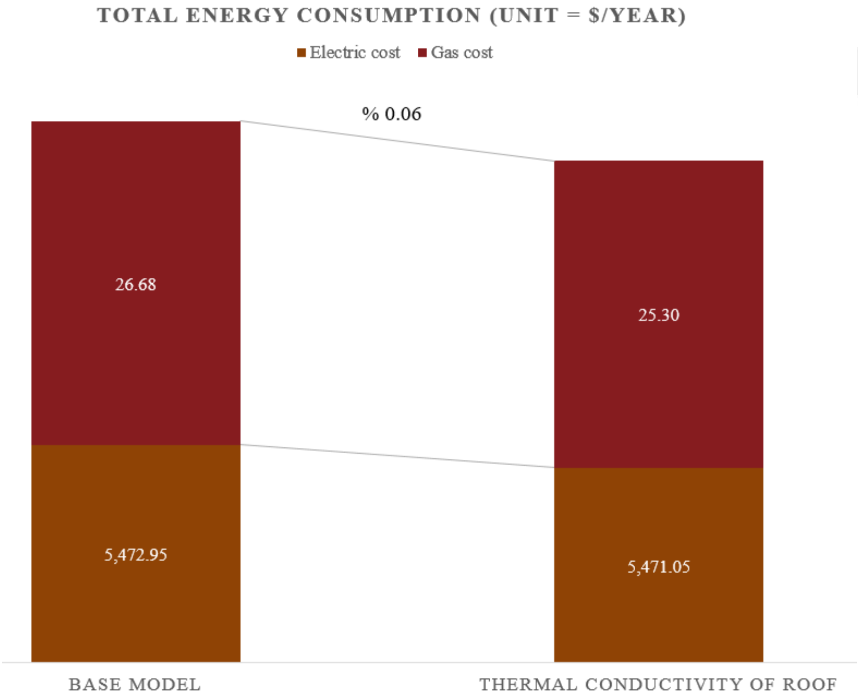


Figure 4.5: Roof Insulation Effect on Cost.

Suggested windows exhibited a high positive effect on space heating by 30.93% or 3300 Kwh/year during cold days of winter because of protecting inside warm air and a 3.03% (50 Kwh/year) positive impact on ventilation fans. Nevertheless, changing windows had no effect on pumps & Auxiliary, exterior usage, equipment usage, and area light. On the other hand, decreasing thermal exchange of windows led to 2.02% which was a 60kWh/year side effect on space cooling due to lack of shading devices and lower thermal exchange, the greenhouse phenomena occurred. Although yearly electric bills cost increased by 0.02% and gas bills cost decreased by 30.39% therefore 7.30$ could be saved in a year (Table 4.10 and Figure 4.7). 4.82% of the entire energy was declined which means 3290 kWh/year for a year; besides, 2.23% positive effect on primary energy is about 3276.38 kWh/year. Table 4.9 and Figure 4.6 are depicted the energy consumption of the window scenario.

Table 4.10: Suggested U-value of Windows [W/m^{2}K].

Scenarios	U-value of Windows
Base model [89]	1.8
Windows	1.1

Table 4.11: Individual Effect of Windows on Energy-Consuming Parameters [%].

	Energy consumption of parameters compared with base							Total energy		Primary energy
Energy consumption	Space Cool	Vent. Fans	Pumps & Aux.	Ext. Usage	Misc. Equip	Area Lights	Space Heat	Electric consumption	Gas Consumption	
Thermal performance of Windows	-2.02	3.03	0.00	0.00	0.00	0.00	30.93	-0.02	30.93	2.23

Table 4.12: Individual Effect of Windows on Cost [%].

Energy consumption parameters	Electric cost	Gas cost	Total cost
Replacing Windows	-0.02	30.93	0.13

4.2.4 Thermal performance of windows and shading devices

Windows of the base model were 10 cm sunk into building shell with 1.8 W/m^{2}K, U-vale, and aluminum frames. The base model had no shading devices except Light color curtains. The aim of this scenario was not only to improve thermal performance but also to improve shading devices. Suggested windows had 1.1 W/m^{2}K U-value with wooden operable frames. In this scenario, 60 cm operable overhang shading tools were considered for all windows which could be used more than 80% during summer hot days to protect from sunlight and used lower than 20% during the cold winter days to use more daylight and heat of the sun. Moreover, roller operable opaque blind with light color was considered for all windows.

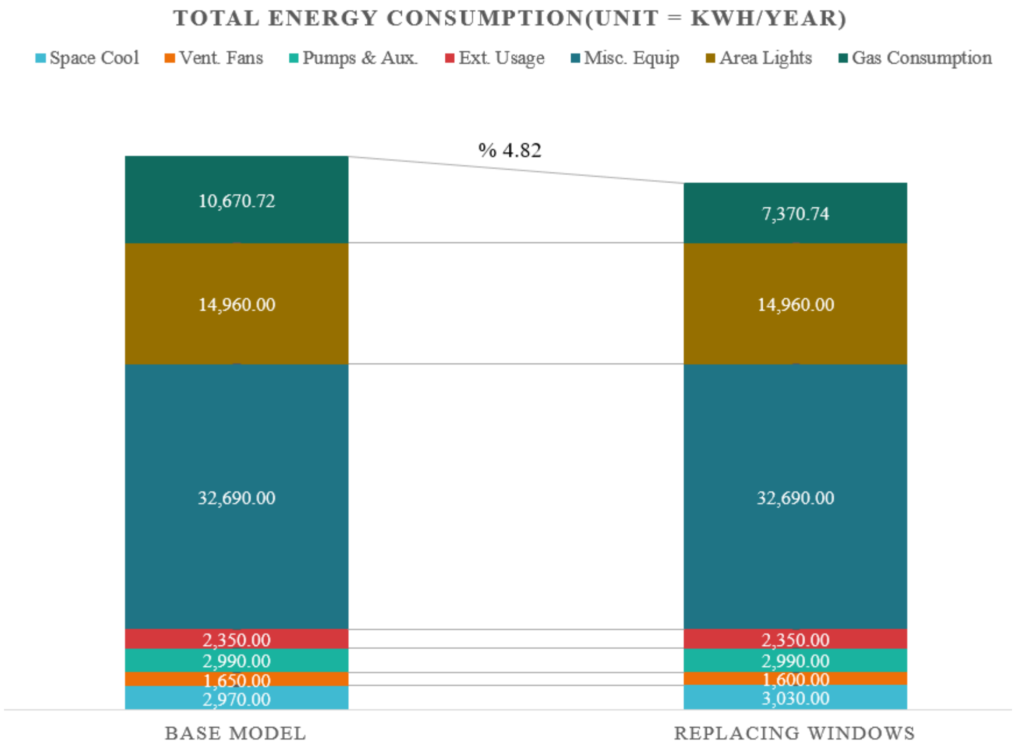


Figure 4.6: Windows Improve Effect on Energy-Consuming Parameters.

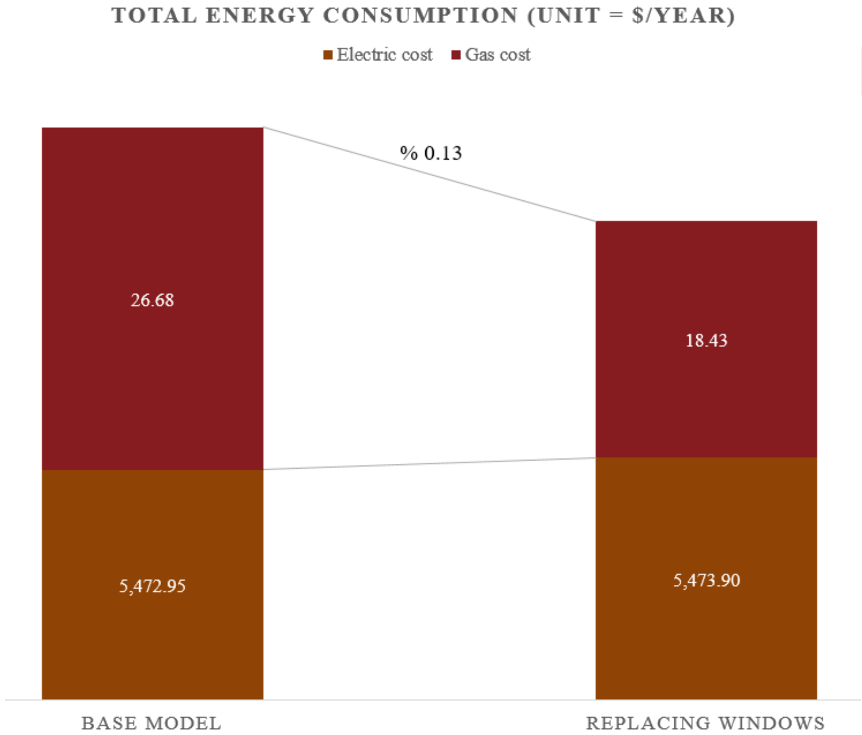


Figure 4.7: Windows Improve Effect on Cost.

This intervention had a 41.58% beneficial outcome for heating space which saved 4437.10 kWh/year, due to profit by the heat of sunlight during cold days and protect the building from losing heat through windows by lower thermal performance. Shading devices preserve the windows from capturing heat during the warm days therefore 23.91% or 710 kWh/year of space cooling energy was reduced; consequently, the useful effect was observed on ventilation fans, exterior energy, and area light 6.67%, 0.85%, and 0.07% respectively which reserved 140 kWh/year. Improving windows did not affect pumps & auxiliary and miscellaneous equipment. Overall profit for final energy is 5287.10 kWh/year or 7.74% saving energy and 6443.10 kWh/year for primary energy which is 4.39% saving. Table 4.11 and Figure 4.8 are represented the energy performance of this scenario. Electric bills cost 1.48% and gas bills 41.58% dropped in comparison to the base model which equals 91.84$ yearly (Table 4.12 and Figure 4.9).

Table 4.13: Individual Effect of Windows & Shading Devices on Energy-Consuming Parameters [%].

Energy consumption	Energy consumption of parameters compared with base							Total energy		Primary energy
	Space Cool	Vent. Fans	Pumps & Aux.	Ext. Usage	Misc. Equip	Area Lights	Space Heat	Electric consumption	Gas Consumption	
Thermal performance of Windows & Shading Devices	23.91	6.67	0.00	0.85	0.00	0.07	41.58	1.48	41.58	4.39

Table 4.14: Individual Effect of Windows & Shading Devices on Cost [%].

Energy consumption parameters	Electric cost	Gas cost	Total cost
Thermal performance of Windows & Shading Devices	1.48	41.58	1.67

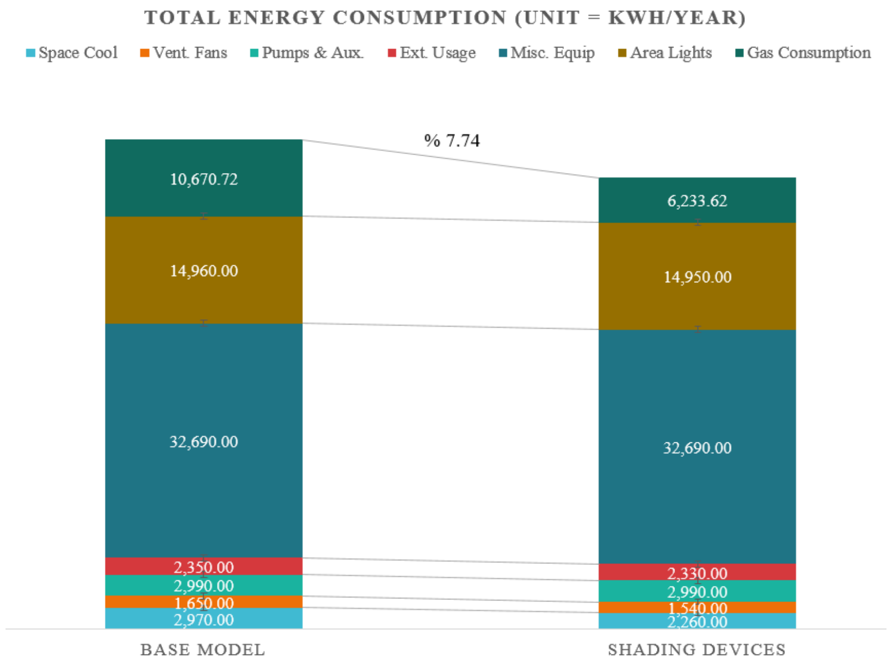


Figure 4.8: Windows Improve and Shading Devices Effect on Energy-Consuming Parameters.

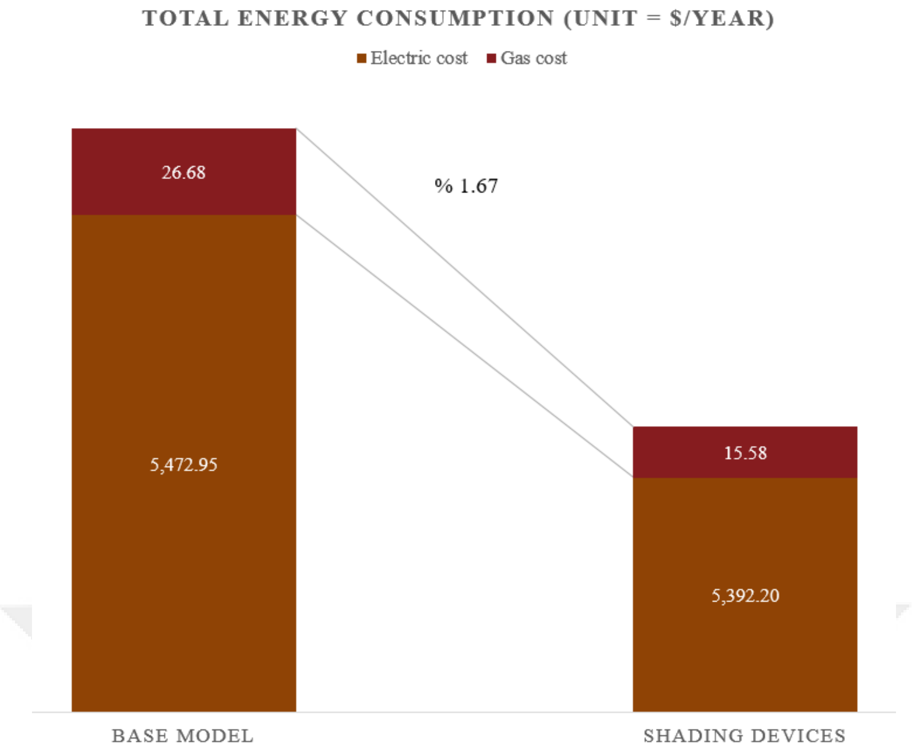


Figure 4.9: Windows Improve and Shading Devices Effect on Cost.

4.2.5 Replacing lamps (LED)

All fluorescent lamps (CFL) were replaced by LED lamps that produce light via light-emitting diodes. LED lamps have longer lifespan (CFL 6,000-10,000 hours = LED 15,000-25,000 hours) and are significantly more efficient than CFL (CFL 15W = LED 9-12W); in other words, LED lamps could save energy about 20%-40% in compare with CFL. In this scenario, 30% saving was considered in terms of a watt per meter square. [93-96]

Replacing lamps had no energy-saving effect on pumps & Auxiliary and equipment usage. This intervention had a dramatically positive impact on area light by 31.15% in other words it could have 4660 kWh decreased the energy consumption and also exterior usage dropped by 30.21% or 710 kWh. Besides, a medium beneficial was appeared for ventilation fans by 1.21% and space cooling by 4.38% which equals to 150 kWh since the heat produced is lower impressively by LED lamps; although, a side effect was recognized on space heating by 5.47% which was 583.21 kWh since CFL lamps were less efficient than LED lamps and lose the energy as heat in term of luminous lux. Relative values are presented in Table 5. Subsequently, the yearly cost of electric bills was reduced by 9.51% while the gas cost rise by 5.47%, however, the total saved could be 522.94$ in a year all values are mentioned in Table 4.13 and Table

4.14. The outcome of final energy spending declined by 7.23% meaning 4936.79 kWh and primary energy was 8.49% which means 12443.99 kWh. Figure 4.10 and Figure 4.11 show the rate of reduction.

Table 4.15: Individual Replacing Lamps on Energy-Consuming Parameters [%].

Energy consumption	Energy consumption of parameters compared with base							Total energy		Primary energy
	Space Cool	Vent. Fans	Pumps & Aux.	Ext. Usage	Misc. Equip	Area Lights	Space Heat	Electric consumption	Gas Consumption	
Individual Replacing Lamps	4.38	1.21	0.00	30.21	0.00	31.15	-5.47	9.58	-5.47	8.49

Table 4.16: Individual Replacing Lamps on Cost [%].

Cost consumption parameters	Electric cost	Gas cost	Total cost
Individual Replacing Lamps	9.58	-5.47	9.51

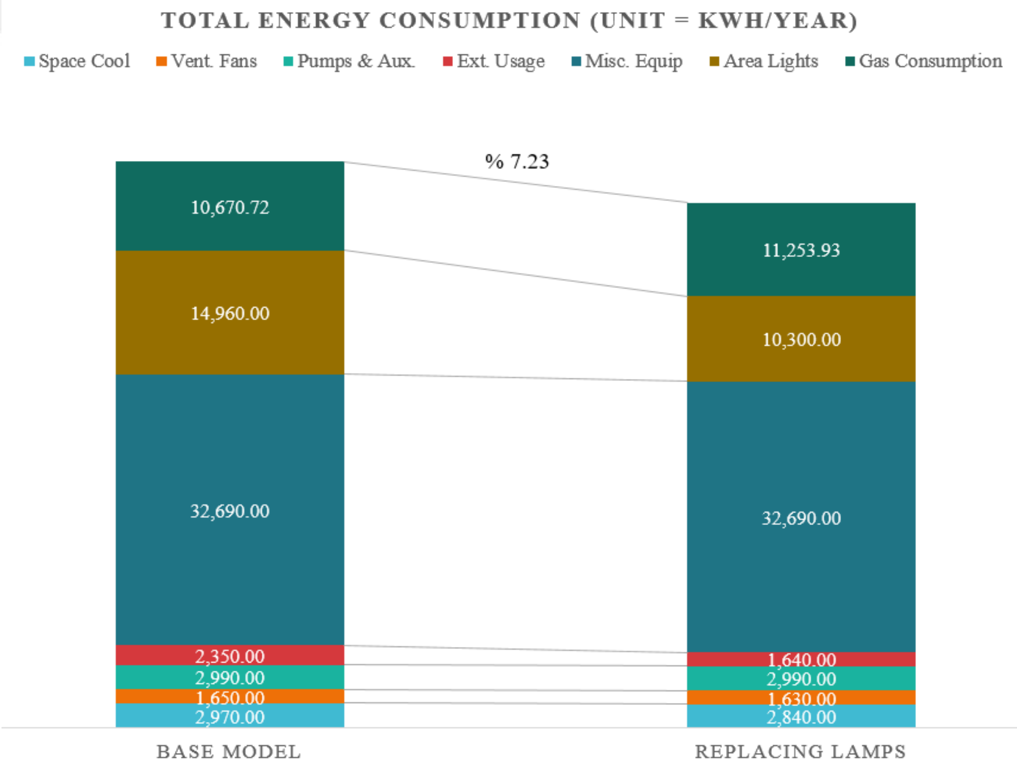


Figure 4.10: Replacing Lamps Effect on Energy-Consuming Parameters.

4.2.6 LED replacing and diming

As mentioned in the previous scenario LED lamps were considered to betterment the lighting system. In this scenario, diming sensors were assumed as well. Sensors were located in the center of each space. Lamps light were diming until 20% based on existing daylight.

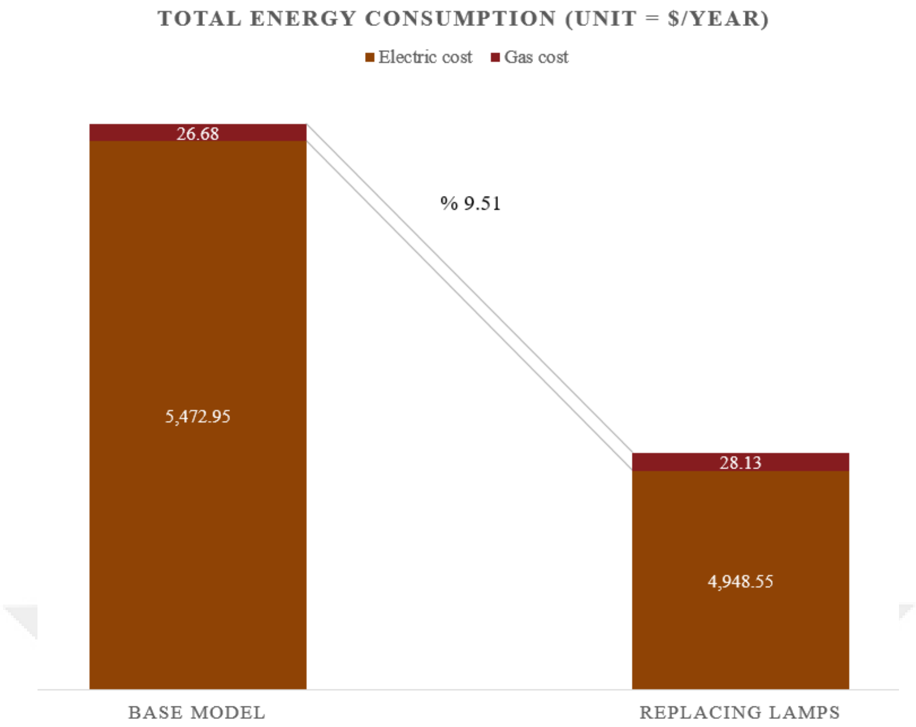


Figure 4.11: Replacing Lamps Effect on Cost of Energy.

Replacing lamps and adding sensors did not affect pumps & Auxiliary and equipment usage. According to the calculated results, positive outcomes were detected on area light by 53.07% that saved 7,940 kWh, exterior usage by 30.21% which was 710 kWh, space cooling 8.42% meaning 250 kWh, and ventilation fans by 1.82% that 30 kWh; while the negative outcome was detected for space heating by 12.39% result in 1,321.75 extra gas usage because of lesser heat radiation by LED lamps. Table 4.15 illustrate mentioned values. Thus, 15.50% of the electric cost was saved albeit gas cost 12.39% rise; however, 845.05$ could be saved in a year that is indicated in Table 4.16. However, the entire final energy spent decreased by 11.14% which means 7,608.25 kWh, and primary energy saved by 19753.05 kWh that is 13.47%. Figure 4.12 and Figure 4.13 are adjusted to represent the rate of influence.

Table 4.17: Individual Replacing Lamps and Diming on Energy-Consuming Parameters [%].

Energy consumption	Energy consumption of parameters compared with base							Total energy		Primary energy
	Space Cool	Vent. Fans	Pumps & Aux.	Ext. Usage	Misc. Equip	Area Lights	Space Heat	Electric consumption	Gas Consumption	
Individual Replacing Lamps and Diming	8.42	1.82	0.00	30.21	0.00	53.07	-12.39	15.50	-12.39	13.47

Table 4.18: Individual Replacing Lamps and Diming on Cost [%].

Cost consumption parameters	Electric cost	Gas cost	Total cost
Individual Replacing Lamps and Diming	15.50	-12.39	15.37

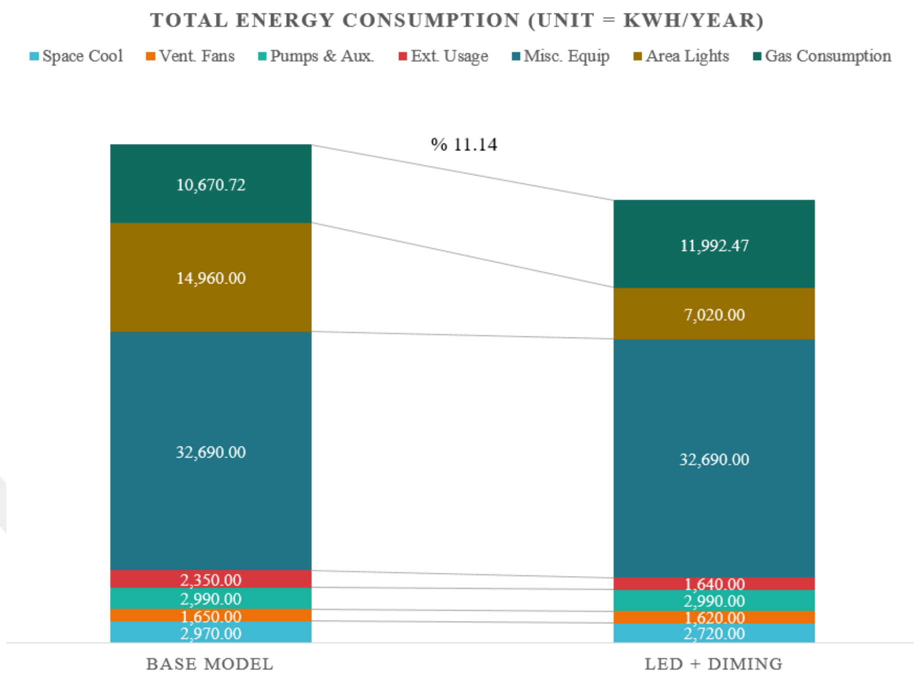


Figure 4.12: Replacing Lamps and Diming Effect on Energy-Consuming Parameters.

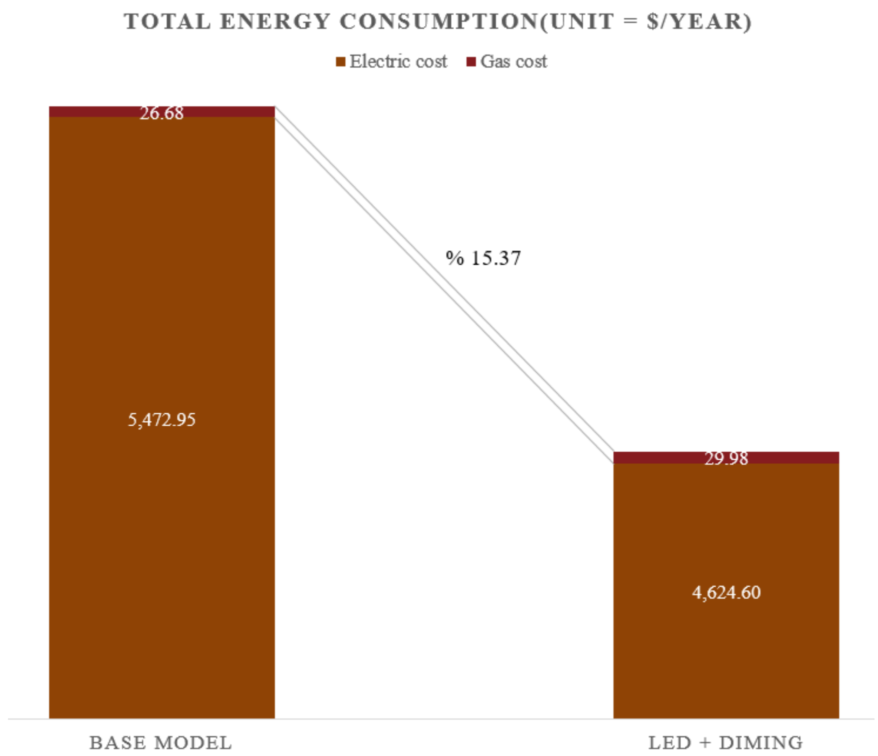


Figure 4.13: Replacing Lamps and Diming Effect on Cost of Energy.

4.2.7 Heat pump

A huge part of consumer energy in the building was allocated to mechanical systems which included cooling, heating, ventilation, air conditioning, and so on systems therefore improving in this part could be visible. Gas energy was consumed for heating all spaces via hot water loop coils in this building. In this part of the study, auditioning a ground source heat pump system to the existing systems was suggested. Based on the location features (soil temperature) and relative studies the optimum temperature for a heat pump is estimated between 12C until 16C [97]. In the next step a true false test was done to distinguish the exact temperature; finally, the optimum temperature of 15C was considered. In other words, if the air temperature was 15C or lower, the heat pump would activate for space heating otherwise existing systems would be active.

The coefficient of performance (COP) determines the performance of the system. It is calculated by the ratio of the energy produced from the heat pump to the amount of energy feed in the system, using equation 4.2.

$$\mathrm{COP} = \frac{\mathrm{Es}}{\mathrm{Ed}} \qquad (4.2)$$

Where Es is energy supply of heat pump, Ed is energy demand of heat pump.

The COP for standard ground heat pump was considered 4.5;[97] which means it could produce 4.5 unit heat energy by 1 unit electric consumption. Therefore producing 10,670.72 kWh heat energy requires 2371 kWh electricity. Total energy consumption for space heating improved by 59.12% that 8300.72 kWh decreased. Heat pump system had a good impact on pumps & Auxiliary energy by 88.28% that means 2639.64 kWh saving, ventilation fans by 39.02% resulting in 643.83 kWh, and exterior energy usage by 0.36% that was 8.45 kWh whereas it left a side effect on cooling space by wasted a little energy in form of heat energy by 2.22% meaning 65.94kWh which negligible by considering decreasing 10.46% final energy consumption that calculated 11526.69 kWh and primary energy improve by 5.48% that means 12690.82 kWh. As a result, the gas cost was eliminated and electric bills cost declined by 1.45% yearly so 107.99$ could save finally. Table 4.17 and Table 4.18 illustrate more specifically; also Figure 4.14 and Figure 4.15 display the rate of the effect.

Table 4.19: Individual Heat Pump on Energy-Consuming Parameters [%].

Energy consumption of parameters compared with base								Total energy		Primary energy
Energy consumption	Space Cool	Vent. Fans	Pumps & Aux.	Ext. Usage	Misc. Equip	Area Lights	Space Heat	Electric consumption	Gas Consumption	
Individual Heat Pump	-2.22	39.02	88.28	0.36	0.00	0.00	59.12	1.45	100	5.48

Table 4.20: Individual Heat Pump on Cost [%].

Cost consumption parameters	Electric cost	Gas cost	Total cost
Individual Heat Pump	1.45	100	1.71

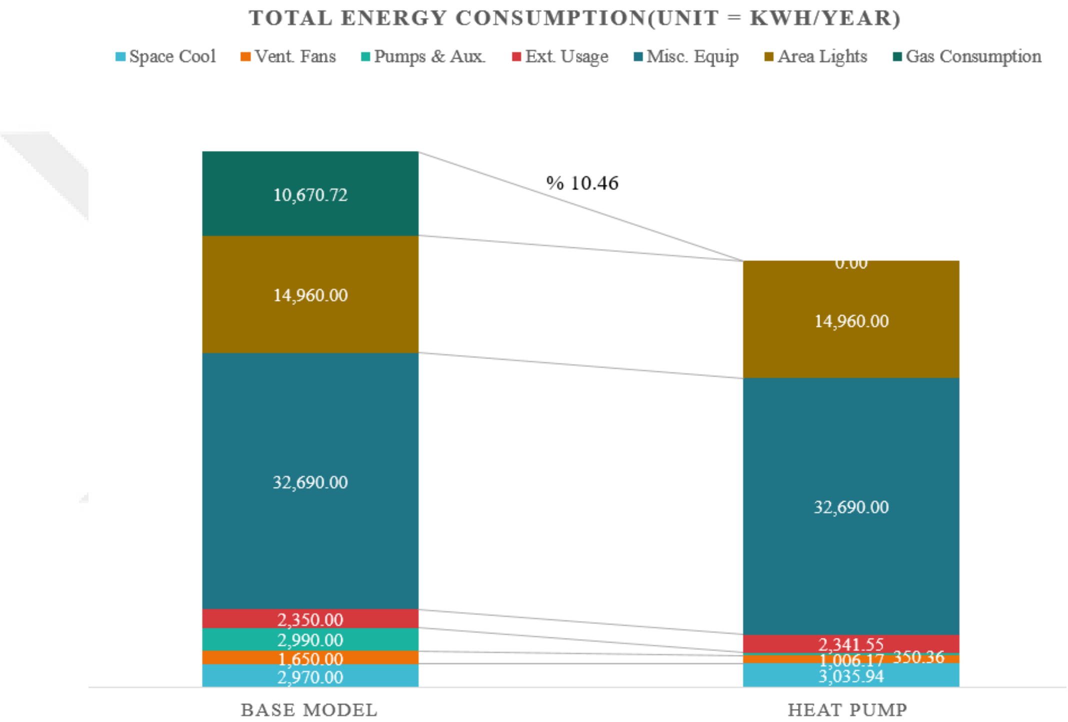


Figure 4.14: Heat Pump Effect on Energy-Consuming Parameters.

4.2.8 PV and batteries

According to the Homer information (given from the NASA library) average daily solar radiation energy intensity for building location is 4.18 (kWh/m^2/day) that shown in Figure 4.16 so there is a good potential for using solar energy. The rate of efficiency in suggested panels was considered 13% due to external effective factors to be near to real life. Solar panels were placed on a surface that was 2 meters above the roof to produce electric energy. Surfaces had 169 m^2 and 187 m^2 areas with an independent structure to transfer their load to the ground, in other words, plates didn't apply additional load to the building; schematic figures were demonstrated in Figure 4.17.

Based on research [98] optimal angle of surfaces was calculated at 34.30 degrees and panels were fixed on the surfaces to decrease the initial cost.

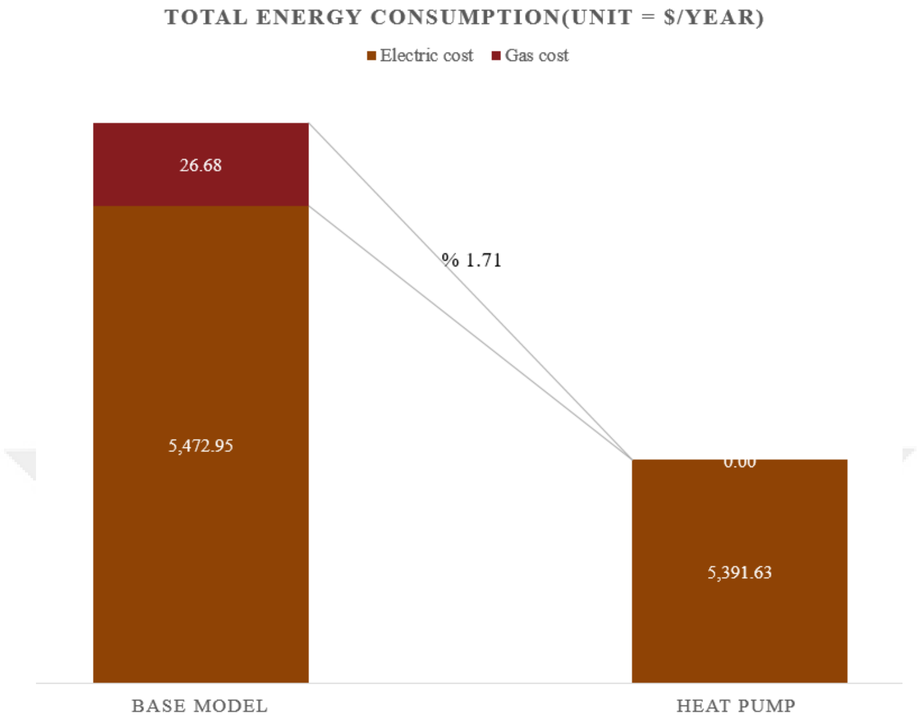


Figure 4.15: Heat Pump Effect on Cost of Energy.

It was planned to use 80 and 72 panels on surfaces by covering 130 m^2 and 117 m^2 area respectively since 50 cm around the surface and 10cm between panels should leave free to decrease shading phenomena and enough space for maintenance and operation. Typical panel size was considered 1.64 m * 0.99 m with 13% efficiency [99, 100]. Total installation power (Q_T) is calculated by multiplying the number of embedded panels with power of each panel, using equation 4.3.

$$Q_T = N \cdot Q_p \tag{4.3}$$

It was calculated to put 152 panels on surfaces. power of each panel 250 W/h considered; so total installed power was about 38 kW/h. The exact information of systems is mentioned in Table 4.23, Table 4.24, Table 4.25.

Table 4.21: Individual PV & Batteries on Energy-Consuming Parameters [%].

Energy consumption	Energy consumption of parameters compared with base							Total energy		Primary energy
	Space Cool	Vent. Fans	Pumps & Aux.	Ext. Usage	Misc. Equip	Area Lights	Space Heat	Electric consumption	Gas Consumption	
Individual Photovoltaic & Batteries	2.02	0.00	0.00	0.00	0.00	0.00	-0.63	84.75	-0.63	78.53

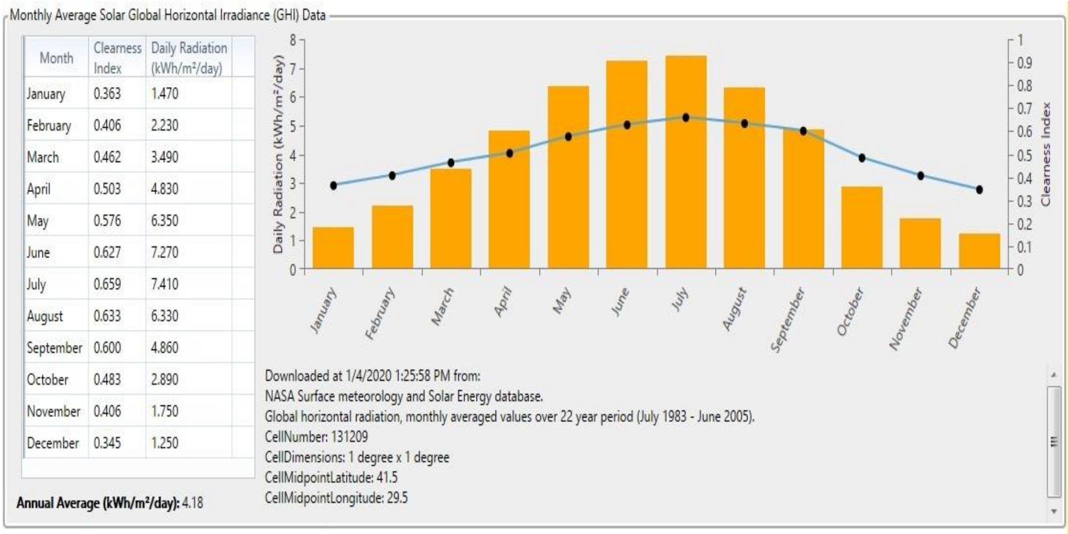


Figure 4.16: Solar Radiation Energy Intensity for Building Location from Homer (given from the NASA library).

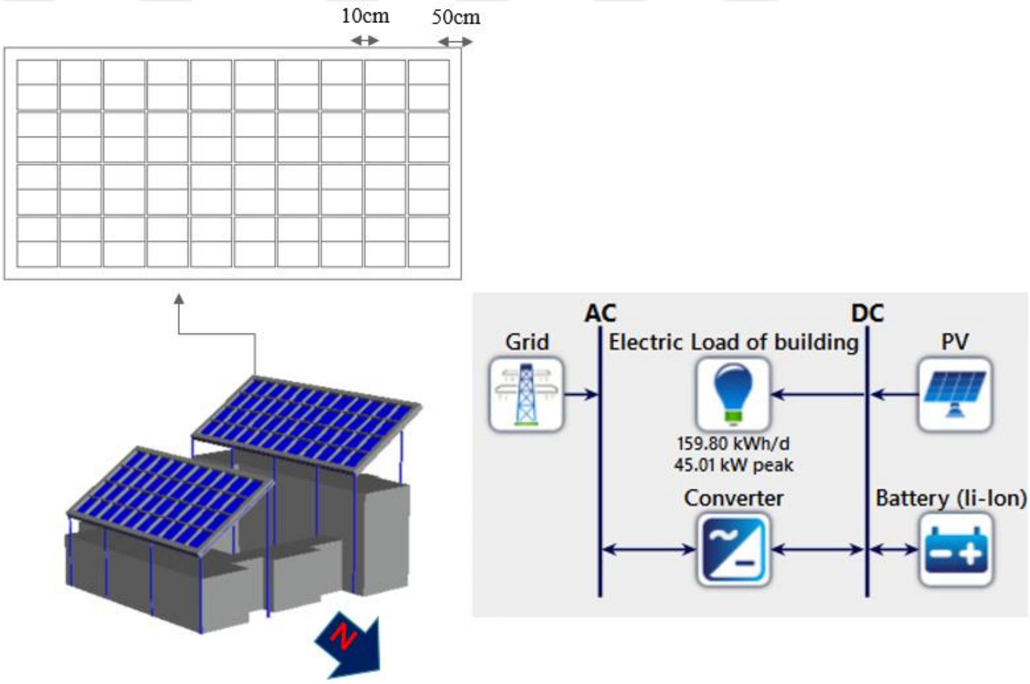


Figure 4.17: Suggested Model for Solar Panels.

Table 4.22: Individual Photovoltaic & Batteries on Cost [%].

Cost consumption parameters	Electric cost	Gas cost	Total cost
Individual Photovoltaic & Batteries	84.75	-0.63	84.33

Table 4.23: Exact Information of Suggested Convertor.

Convertor	
Life Time	15 years
Efficiency	95%

Table 4.24: Exact Information of Suggested Battery.

Lithium-ion Battery	
Nominal Voltage	55.5V
Nominal Capacity	5.77kWh = 104Ah
Roundtrip Efficiency	97%
Max Charge Rate	52A/Ah
Max Charge & Discharge Current	52A
Life Time	10 years
Minimum storage life	4 Years
The initial state of charge	90%
Minimum state of charge	10%
Number of Batteries	4

Table 4.25: Exact Information of Suggested Solar Panels.

Generic flat-plate PV	
Annual Average Irradiation	4.18 ($kWh/m^2/day$)* 365 = 1525.7 ($kWh/m^2/year$)
Panels Size	1.64m * 0.99m = $1.62m^2$
Efficiency	13 %
Rated Capacity	1kW
Temperature Coefficient	-0.5
Operating Temperature	47C
Life Time	25 years
Panels Angels	34.30
Number of Panels	80 + 72
Total Power	38kW/h

Panels did not affect the energy consumption of parameters; however, surfaces had a positive influence on space cooling by 2.02% which was 60 kWh, and a little negative influence on space heating by 0.63% which was 67.41 kWh due to shading on the roof. Suggested panels could produce 48,762 kWh/year based on the Homer calculation, which means 84.75% of electric consumption could be compensated by 152 panels.

Therefore 84.33% of bills cost could be saved in a year, meaning 4637.92 $. Finally, total final energy using improve by 71.40% calculated at 48754.59 kWh and primary energy saved about 78.53% which means 115152.51 kWh. Mentioned values were taken from Table 4.21 and Table 4.22 besides, Figure 4.18 and Figure 4.19 represent the situation.

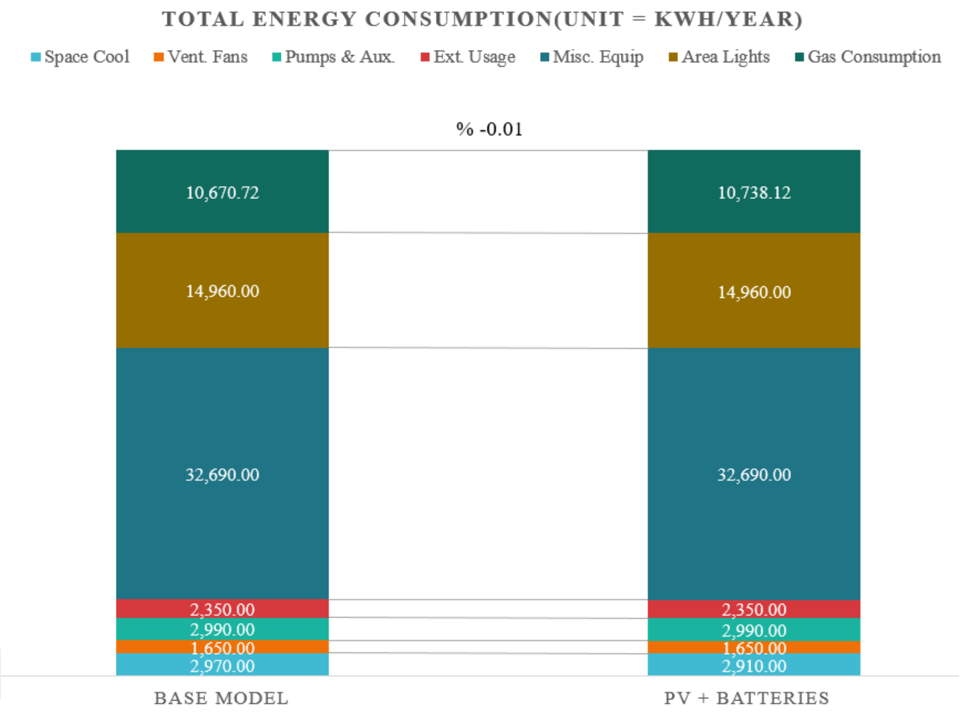


Figure 4.18: Photovoltaic & Batteries Effect on Energy-Consuming Parameters.

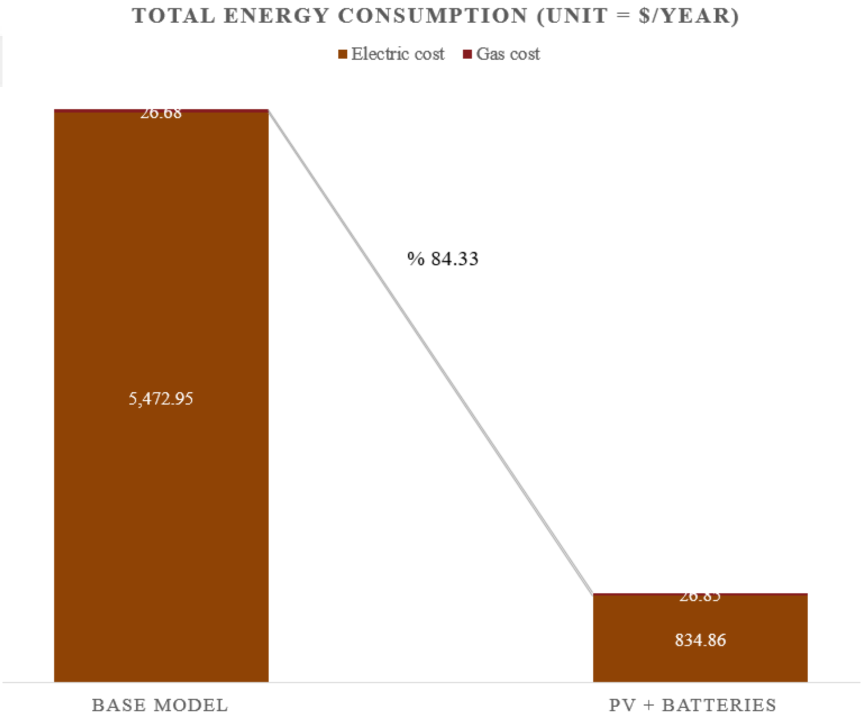


Figure 4.19: Photovoltaic & Batteries Effect on Cost of Energy.

4.3 Result of each Intervention

The impact of each intervention on energy consumption parameters was investigated separately. The highest positive effect on electricity is relative to solar systems by about 85% and on gas consumption is relative to heat pump by 100% also improving wall insulation declare 46% good influence on gas usage. Replacing windows have a medium effect of 31% and replacing lamps in addition to dimming sensors indicates 15.5%. Replacing lamps have low effect on electric consumption by 10% and thermal performance of roof show low effect by 5% on gas consumption. Besides, shading device, heat pump, and thermal performance of walls and roof display very low effect on electric consumption by 1.48%, 1.45%, 0.03%, 0.03% respectively. Although overall results are positive, negative effects on gas consumption appear by replacing lamps and diming sensors by -12.40%, replacing lamps -5.47%, solar systems by -0.63%; also side effects appear by replacing windows on electric consumption by -0.02%. The main decision criteria is primary energy that depends on electric consumption more than gas consumption from the highest to lowest in order solar systems by 78.53%, replacing lamps and dimming sensors by 13.47%, replacing lamps by 8.49%, heat pump by 5.48%, shading devices by 4.49%, the thermal performance of walls by 3.36%, replacing windows by 2.23%, thermal performance of roof by 0.41%. Table 4.26 represents energy consumption amount and Table 4.27 and Figure 4.20 show the rate of improvement in comparison with the base model.

Table 4.26: Energy Consuming of Individual Scenarios' Parameters [kWh/Year].

	Energy consumption of parameters							Total energy		
Energy consumption	Space Cool	Vent. Fans	Pumps & Aux.	Ext. Usage	Misc. Equip	Area Lights	Space Heat	Electric consumption	Gas Consumption	Primary energy
Base Model	2,970.00	1,650.00	2,990.00	2,350.00	32,690.00	14,960.00	10,670.72	57,610.00	10,670.72	146,630.32
Thermal performance of Walls	3,030.00	1,570.00	2,990.00	2,350.00	32,690.00	14,960.00	5,796.95	57,590.00	5,796.95	141,709.35
Thermal performance of Roof	2,960.00	1,640.00	2,990.00	2,350.00	32,690.00	14,960.00	10,119.74	57,590.00	10,119.74	146,032.14
Replacing Windows	3,030.00	1,600.00	2,990.00	2,350.00	32,690.00	14,960.00	7,370.74	57,620.00	7,370.74	143,353.94
Shading Devices	2,260.00	1,540.00	2,990.00	2,330.00	32,700.00	14,950.00	6,233.62	56,770.00	6,233.62	140,187.22
Replacing Lamps (LED)	2,840.00	1,630.00	2,990.00	1,640.00	32,690.00	10,300.00	11,253.93	52,090.00	11,253.93	134,186.33
LED + Diming	2,720.00	1,620.00	2,990.00	1,640.00	32,690.00	7,020.00	11,992.47	48,680.00	11,992.47	126,877.27
Heat Pump	3,035.94	1,006.17	350.36	2,341.55	32,690.00	14,960.00	2,370.00	56,754.02	0.00	133,939.50
PV + Batteries	2,910.00	1,650.00	2,990.00	2,350.00	32,690.00	14,960.00	10,738.12	8,788.00	10,738.12	31,477.80

The total cost is sensitive to electric cost due to the high cost of electricity. The highest to the lowest positive influence of cost appear in order solar system by 84.33%, replacing lams and dimming sensors by 15.37%, replacing lamps by 9.51%, heat pump by 1.71%, shading devices by 1.67%, the thermal performance of walls by 0.26%, replacing windows by 0.13%, thermal performance of roof by 0.06%. Specific information are mentioned in Table 4.28 and Table 4.29.

Table 4.27: Influence of Scenarios in comparison with the Base Model [%].

	Energy consumption of parameters compared with base						Total energy		Primary energy
	Space Cool	Vent. Fans	Pumps & Aux.	Ext. Usage	Area Lights	Space Heat	Electric consumption	Gas Consumption	
Thermal performance of Walls	-2.02	4.85	0.00	0.00	0.00	45.67	0.03	45.67	3.36
Thermal performance of Roof	0.34	0.61	0.00	0.00	0.00	5.16	0.03	5.16	0.41
Replacing Windows	-2.02	3.03	0.00	0.00	0.00	30.93	-0.02	30.93	2.23
Shading Devices	23.91	6.67	0.00	0.85	0.07	41.58	1.48	41.58	4.39
Replacing Lamps (LED	4.38	1.21	0.00	30.21	31.15	-5.47	9.58	-5.47	8.49
LED + Diming	8.42	1.82	0.00	30.21	53.07	-12.39	15.50	-12.39	13.47
Heat Pump	-2.22	39.02	88.28	0.36	0.00	59.12	1.45	100.00	5.48
PV + Batteries	2.02	0.00	0.00	0.00	0.00	-0.63	84.75	-0.63	78.53

Table 4.28: Energy Cost of Individual Scenarios [$/Year].

Cost consumption parameters	Electric cost	Gas cost	Total cost
Base Model	5,472.95	26.68	5,499.63
Thermal performance of Walls	5,471.05	14.49	5,485.54
Thermal performance of Roof	5,471.05	25.30	5,496.35
Replacing Windows	5,473.90	18.43	5,492.33
Shading Devices	5,392.20	15.58	5,407.78
Replacing Lamps (LED)	4,948.55	28.13	4,976.68
LED + Diming	4,624.60	29.98	4,654.58
Heat Pump	5,391.63	0.00	5,391.63
PV + Batteries	834.86	26.85	861.71

Table 4.29: Influence of Scenarios in Comparison with Base Model [%].

Cost consumption parameters	Electric cost	Gas cost	Total cost
Thermal performance of Walls	0.03	45.67	0.26
Thermal performance of Roof	0.03	5.16	0.06
Replacing Windows	-0.02	30.93	0.13
Shading Devices	1.48	41.58	1.67
Replacing Lamps (LED)	9.58	-5.47	9.51
LED + Diming	15.50	-12.39	15.37
Heat Pump	1.45	100.00	1.71
PV + Batteries	84.75	-0.63	84.33

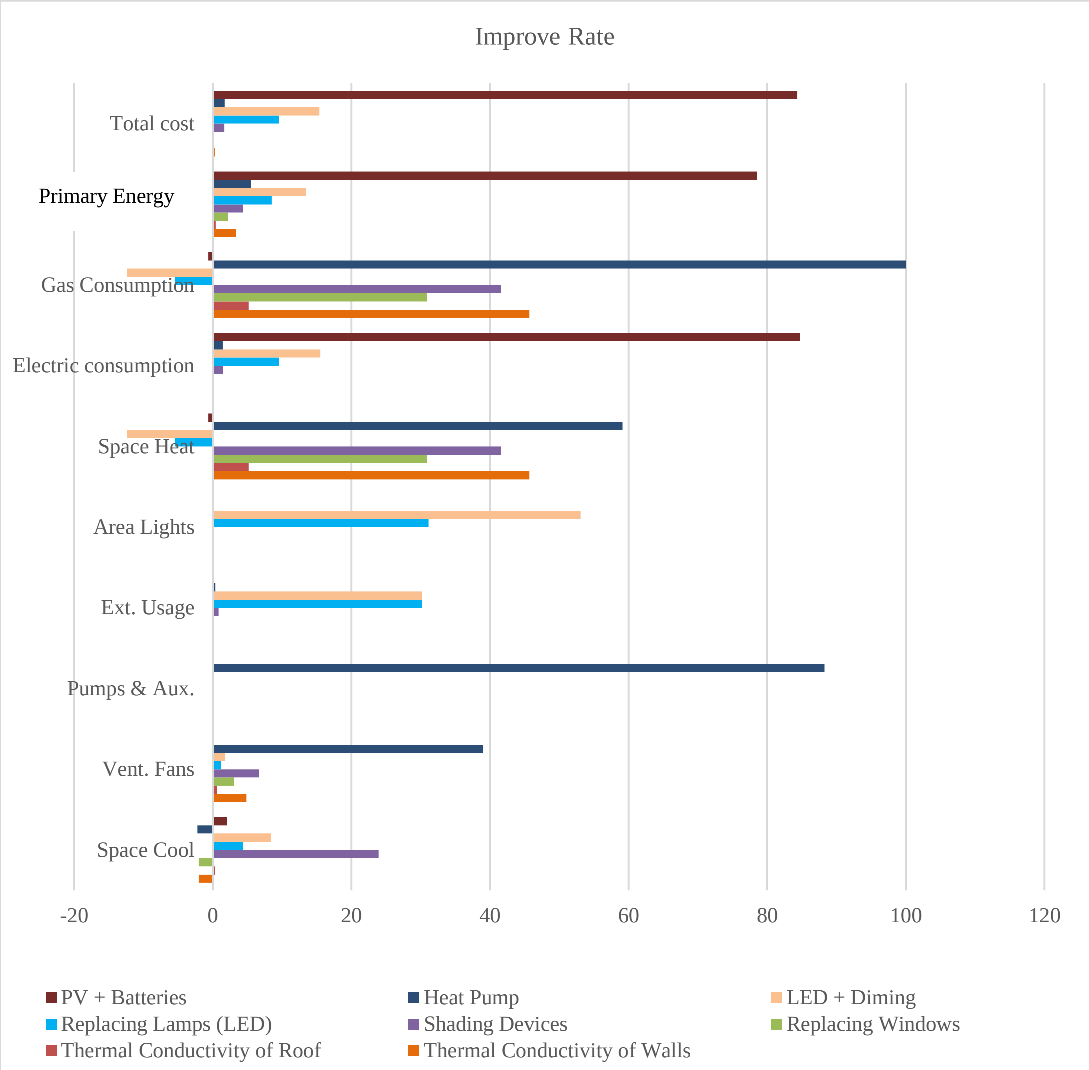


Figure 4.20: Influence of Scenarios on Energy-Consuming Parameters in comparison with the Base Model (%).

4.4 Comparison Active and Passive Interventions

Suggested scenarios were divided into two parts active and passive strategies. Passive strategies include thermal performance of walls, roof, windows, and shading devices that can be an envelop retrofitting strategy. Active strategies include replacing lamps, dimming sensors, heat pumps, and solar systems. Mentioned passive strategies were affected gas consumption more than electric consumption; whereas active strategies had different behavior and could cover the whole requirement energy. Based on the final results active strategy could cover requirement energy and convert building to zero consumption building; however, passive strategies improve gas consumption by 82.18% and electric consumption by 1.63% consequently primary energy decline by 7.49% also total cost decline by 2.02%.

Active strategies: According to the previous assumptions, the soil source heat pump has potential to cover the gas requirement of the building. Solar systems supply 85% which means 48,822.00 Kwh/year of electric consumption so the remaining amount of energy could save by reducing electric usage of lighting systems. Although improvement lighting system leads to a negative effect on gas consumption, a reasonable reduction amount is possible by replacing lamps that are around 10% that was about 5,520.00 Kwh/year; in the following steps dimming sensors are applied to decline electric consumption to 15.50% by about 8,930.00 Kwh/year. Based on the results mentioned in Table 4.26 and Table 4.27 electric reductions are more effective in comparison with gas decline. The improvement rate from highest to lowest is solar systems by 78.53% about 115,152.51 Kwh/year, replacing lamps with dimming sensors by 13.47% by about 19,753.05 Kwh/year, replacing lamps by 8.49% that means 12,443.99 Kwh/year, and heat pump by 5.48% by about 12,690.82 Kwh/year. Finally dropping energy consumption until zero can be possible by improving lighting systems, solar systems, and heat pumps.

Cost analysis is one of the important contributions since the outcome of the analysis will determine whether the project is financially feasible to apply. As demonstrated in Table 4.28 and Table 4.29 electricity is more expensive than gas. Profit from high to low could be a solar system by 84.33% that means 4637.92$ in a year, improving lighting systems by replacing lamps and dimming sensors leads to 15.37% that is about 845.05$ in a year, and heat pump save 1.71% that is about 107.99$. Thus, in the active final scenario, 5,545.27$ electric cost in addition 26.68$ gas cost saved that means 5,572$ could be saved in a year. If 50 years exiting lifetime puts into count, the saving amount will be around 278,600$.

Passive strategies: All of the consumer parameters presented profitable results. The maximum desirable influence was determined in space heating by 82.12% which was about 8,768.69 Kwh/year. Also, 23.91% of energy was saved by the cooling system by about 710 Kwh/year. Then ventilation fans consumed 12.12% lower energy in comparison with the base model that means 200 Kwh/year. Moreover, 30 Kwh/year positive impact was found out by exterior usage and area light. Finally, electric consumption improved by 1.63% about 940 Kwh/year, and gas consumption improved by 82.18% which calculated 8,768.69 Kwh/year. Consequently, primary energy decreased by 7.49% which expressed 10,987.09 Kwh/year (electric consumption is

2.36 times more effective than gas consumption on primary energy). Thus, not only overall values but also each consumer parameter demonstrated positive effects on the energy performance of the building in a year. In the following steps, the calculated values will investigate hourly to analyze more specifically and increase the energy performance. Table 4.30 and Table 4.31 is illustrated values.

Cost investigation declared profit from high to low could be shading device by about 1.67% that means 91.84$ in a year, the thermal performance of walls by 0.26% that is about 14.08$ in a year, replacing windows by 0.13% that is about 7.30$ in a year, and thermal performance of roof by 0.06% that is about 3.28 $ in a year. Thus, in the passive final scenario, 89.30$ electric cost in addition to 21.92$ gas cost saved that means 111.22$ could be saved in a year. If 50 years exiting lifetime puts into count, the saving amount will be around 5,561$. Table 4.32 represents cost amount and Table 4.33 shows the rate of improvement in comparison with the base model.

Table 4.30: Energy Consuming of Individual Final Scenarios [kWh/Year].

	Energy consumption of parameters							Total energy		Primary energy
Energy consumption	Space Cool	Vent. Fans	Pumps & Aux.	Ext. Usage	Misc. Equip	Area Lights	Space Heat	Electric consumption	Gas Consumption	
Base Model	2,970.00	1,650.00	2,990.00	2,350.00	32,690.00	14,960.00	10,670.72	57,610.00	10,670.72	146,630.32
Active Strategies	2,713.99	976.14	350.43	1,631.61	32,690.00	7,020.00	2,678.54	0.00	0.00	0.00
Passive Strategies	2,260.00	1,450.00	2,990.00	2,330.00	32,690.00	14,950.00	1902.03	56,670.00	1902.03	135,643.23

Table 4.31: Influence of Final Scenarios in comparison with the Base Model [%].

	Energy consumption of parameters compared with base						Total energy		Primary energy
Energy consumption	Space Cool	Vent. Fans	Pumps & Aux.	Ext. Usage	Area Lights	Space Heat	Electric consumption	Gas Consumption	
Active Strategies	8.62	40.84	88.28	30.57	53.07	74.90	100.00	100.00	100.00
Passive Strategies	23.91	12.12	0.00	0.85	0.07	82.18	1.63	82.18	7.49

Table 4.32: Energy Cost of Individual Scenarios [$/Year].

Cost consumption parameters	Electric cost	Gas cost	Total cost
Base Model	5,472.95	26.68	5,499.63
Active Strategies	0.00	0.00	0.00
Passive Strategies	5,383.65	4.76	5,388.41

Table 4.33: Influence of Scenarios in Comparison with Base Model [%].

Cost consumption parameters	Electric cost	Gas cost	Total cost
Active Strategies	100.00	100.00	100.00
Passive Strategies	1.63	82.18	2.02

5. HOURLY STATISTICAL ANALYSIS OF ENVELOP RETROFITING

5.1 Detailed Analyses on the whole Envelop Retrofitting

In this step, four suggested interventions as walls, roof insulations, window replacements, shading device integration were applied to the case study and simulated by eQUEST to analyze the energy performance of the final suggested scenario. All of the consumer parameters presented profitable results. The maximum desirable influence was determined in space heating by 82.12% which was about 8,768.69 Kwh/year. Also, 23.91% of energy was saved by the cooling system by about 710 Kwh/year. Then ventilation fans consumed 12.12% lower energy in comparison with the base model that means 200 Kwh/year. Moreover, 30 Kwh/year positive impact was found out by exterior usage and area light. Finally, electric consumption improved by 1.63% about 940 Kwh/year, and gas consumption improved by 82.18% which calculated 8,768.69 Kwh/year. Consequently, primary energy decreased by 7.49% which expressed 10,987.09 Kwh/year (electric consumption is 2.36 times more effective than gas consumption on primary energy).

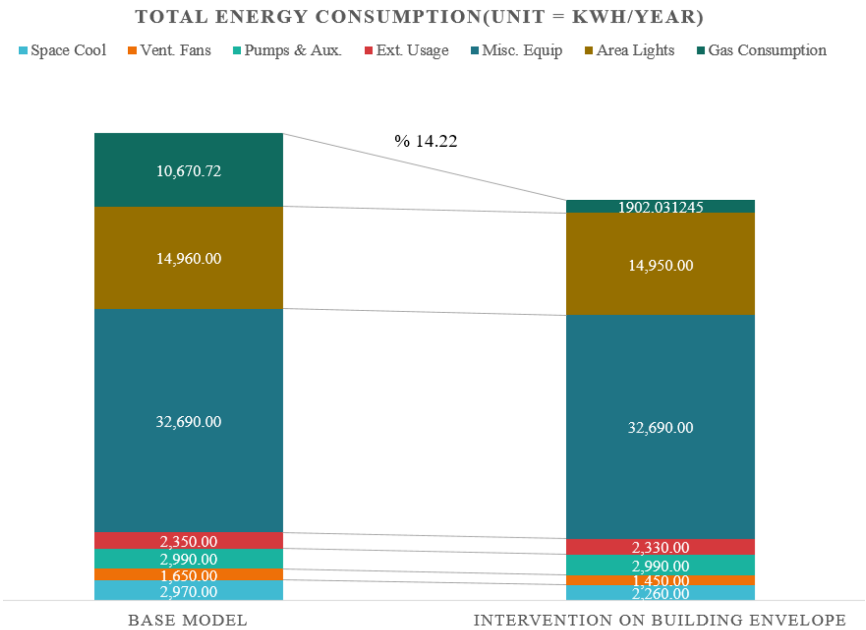


Figure 5.1: Envelope Interventions’ Effect on Energy-Consuming Parameters.

Table 4.26 is illustrated the exact values also Table 4.27 and Figure 5.1 is shown improve rate. Thus, not only overall values but also each consumer parameter demonstrated positive effects on the energy performance of the building in a year. In the following steps, the calculated values will investigate hourly to analyze more specifically and increase the energy performance.

All results of envelope intervention were evaluated by using RStudio [101] in terms of hourly data identification, distribution, the hourly influence of envelope intervention on energy consumption as well as parameters' dependency by using logic mentioned in the methodology part.

5.2 Hourly Identification for Intervention on Building Envelope

According to the hourly calculations, envelop intervention has a high influence on space heating by 85.31% than space cooling by 16.16%, and finally a lower effect on ventilation fans by 11.26% other parameters were not mentioned due to zero or near to zero influence; consequently, the highest effect declared in the gas consumption by about 85 % improvement and a percent in electric consumption. Also, a 12 % positive effect is shown in primary energy. Space cooling worked 1203 hours, ventilation fanes 2849 Hours, and space heating 495 hours in a year. The minimum range was relative to ventilation fans while the maximum range was for space cooling. More specific information is represented in Table 5.1 that calculated by using equation 5.1.

$$\mathrm{Q1} = \frac{1}{4}\,(\mathrm{n}+1)^{\mathrm{th}}\ \mathrm{term} \tag{5.1}$$

If n is odd, then: $$\mathrm{M} = \left(\frac{\mathrm{n}+1}{2}\right)^{\mathrm{th}}\ \mathrm{term}$$

If n is even, then: $$\mathrm{M} = \frac{\left(\frac{\mathrm{n}}{2}\right)^{\mathrm{th}}\ \mathrm{term} + \left(\frac{\mathrm{n}}{2}+1\right)^{\mathrm{th}}\ \mathrm{term}}{2}$$

$$\bar{\mathrm{x}} = \frac{1}{n}\sum_{i=0}^{n} x_i$$

$$\mathrm{Q3} = \frac{3}{4}\,(\mathrm{n}+1)^{\mathrm{th}}\ \mathrm{term}$$

Where Q1 is first quarter [%], n is number of work hours, M is median amount [%], $\bar{\mathrm{x}}$ is mean of influence on energy consumption [%], x is influence of intervention per hour [%], Q3 is third quarter of hourly influence of envelope intervention on energy consumption [%].

Table 5.1: Summarize Hourly Influence of Envelope Intervention on Energy Consumption in a Year [%].

Variable	*n	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Space Cool	1203	-143.19	19.29	25.60	16.16	29.62	38.23
Vent. Fans	2849	-9.62	-3.94	19.60	11.26	19.60	40.77
Space Heat	495	17.31	81.44	89.78	85.31	95.02	99.78
Electric Consumption	8760	-16.67	0.00	0.00	0.74	0.00	15.87
Gas Consumption	495	17.31	81.44	89.78	85.31	95.02	99.78
Primary energy	8760	-17.97	0.00	0.00	12.00	1.02	99.97

*n: Work hours

Overall results are positive but side effects are viewed in space cooling and ventilation fans by improving envelop of the building. 112 negative values appeared in the hourly data of space cooling during the transition seasons which represent 9% of data. 958 hours side effects came out for ventilation fans that calculated 34% of data during the winter months (mostly 9 AM – 6 PM) although the negative amount of values are lower than other factors. The relative cumulative distribution function (CDF) plot is the probability that the variable takes a value less than or equal to x, as shown in figure 5.2 calculated by using equation 5.2.

$$F(x) = \Pr[X \leq x] = a \tag{5.2}$$

This can be expressed mathematically as

$$F(x) = \int f(\mu)\, d\mu$$

Where $-150 \leq X \leq 150$ and $x \leq 0$

Data are distributed from lowest to highest in Figure 5.2 to analyze the dissemination of data and compare with each other. The red line represents cooling performance that has the highest amount of negative influence hours. The green line shows ventilation fans and blue line shows space heat of intervention influence per hour. There is not any negative influence on space heating so space heat is ignored in the next steps.

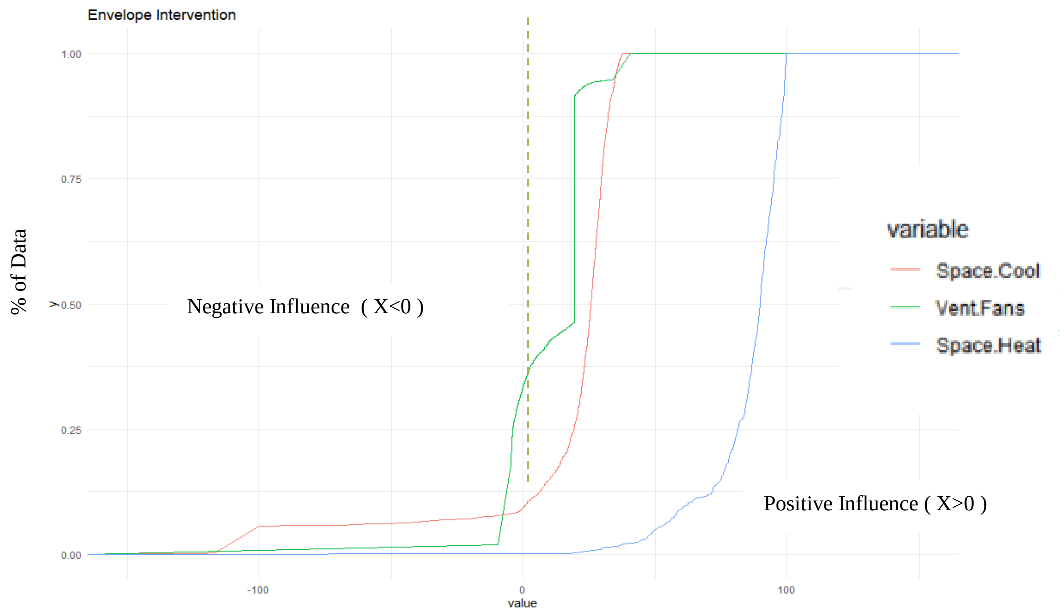


Figure 5.2: Distribution of Improvement Rate (%).

Consequently, 1041 worst value that is about 12% in electric consumption, and 425 which means 5% in primary energy appeared due to negative effects on the cooling system and ventilation fans. Besides, the hourly influence of each parameter and overall consumption based on time series was displayed in Figure 5.3 and Figure 5.4 to indicate the amount of data in relative time; also side effects were highlighted via red boxes (x < 0).

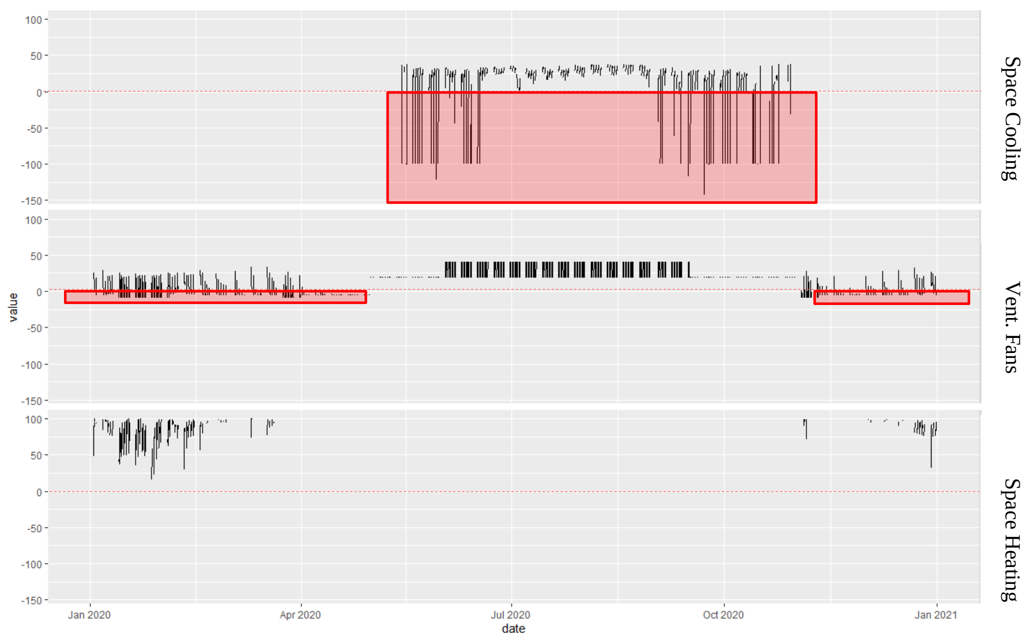


Figure 5.3: Hourly Influence of Envelope Intervention on Energy Consumption Parameters [%].

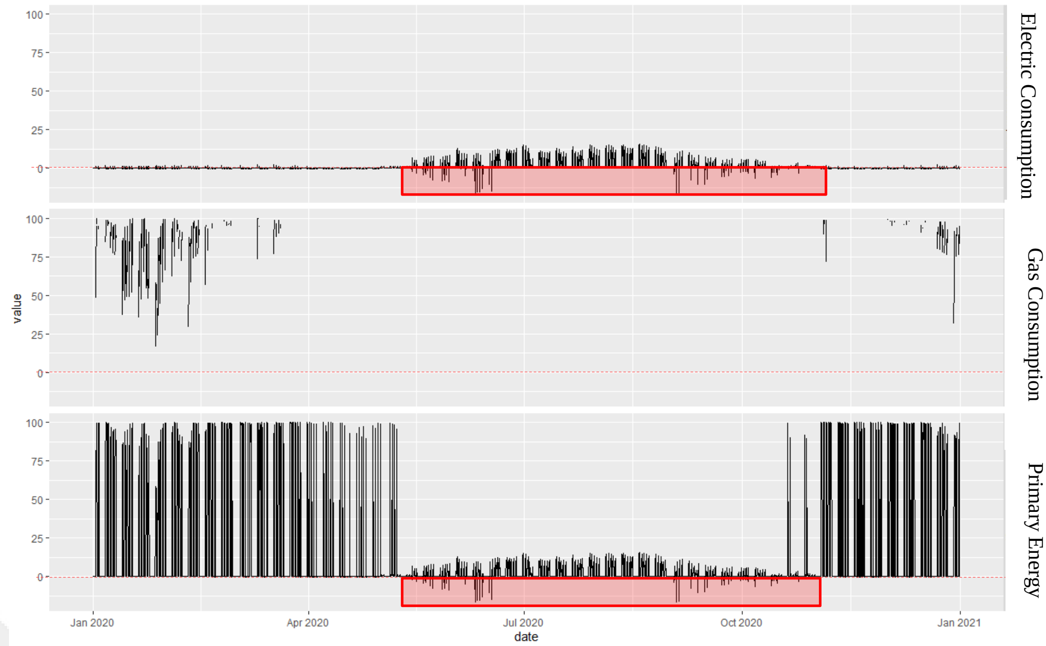


Figure 5.4: Hourly Influence of Envelope Intervention on Overall Energy Consumption [%].

5.3 Interpretation of hourly improvement trends for Building Envelope

5.3.1 Assess intervention on building envelope

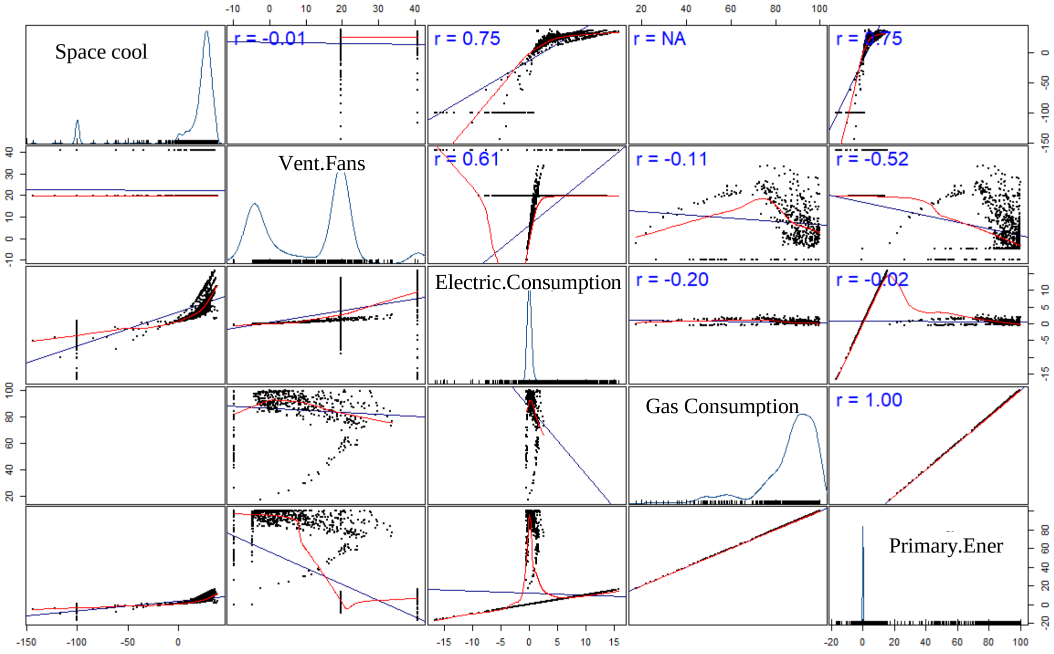
The hourly improvement rate of the intervention envelope was used to interpret trends statistically. Shapes of scatters were indicated along the main dimeter of the below figure 5.5 In statistics, the correlation coefficient "r" measures the strength and direction of a linear relationship between two variables on a scatterplot. The red line shows the correlation (in statistics, correlation or dependence show the relationship between values) and r values show the rate of dependence. There were both positive and negative correlations. The value of a correlation coefficient ranges between -1 and +1. The correlation coefficient is +1 in the case of a perfect direct (increasing) linear relationship (correlation), −1 in the case of a perfect inverse (decreasing) linear relationship (anticorrelation). The coefficient of correlation is calculated by equation 5.3.

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{5.3}$$

Where x and y are parameters that represent influence of intervention per hour [%].

The maximum uphill positive linear relationship was between gas consumption and primary energy (r = 1). The main concern in this study is progress primary energy.

Side effects occurred for space cooling with a 0.75 correlation between electric consumption and primary energy so if cooling performance increases, the electric and primary energy performance increase by 0.75 dependencies. Moreover, ventilation fans showed the highest anticorrelation with primary energy by -0.52 and 0.61 correlation with electric consumption due to anticorrelation ventilation fans could be ignored in this step since negative correlation express if performance of ventilation fans decreases, the primary energy increase by -0.52 dependency. Therefore, the key factor to increase performance is improved hourly cooling performance. Furthermore, Locally Weighted Scatterplot Smoothing (lowess) Smoothing was shown by blue lines to foresee trends based on the data relationship. As depicted in Figure 5.5.



Parameters	Correlation or Dependence
Space cool - Vent.Fans	-0.01
Space cool - Electric Consumption	0.75
Space cool - Gas Consumption	NA
Space cool - Primary energy	0.75
Vent.Fans - Electric Consumption	0.61
Vent.Fans - Gas Consumption	-0.11
Vent.Fans - Primary energy	-0.52
Electric Consumption - Gas Consumption	-0.20
Electric Consumption - Primary energy	-0.02
Gas Consumption - Primary energy	1.00

Figure 5.5: Dependency of parameters in Envelope Intervention Scenario.

5.4 Hourly effect of Envelope Retrofitting on Cooling Performance

Based on the calculated results, improvement in hourly cooling performance leads to be near the main object that is raised the efficiency of the building. Although yearly and monthly improvement values are positive because of 1091 hours good influence, 47 negative values appeared in the hourly data of space cooling during the transition seasons; besides, the cooling system in the retrofitted scenario worked 65 (100% negative) hours more than the base model in a year. The total negative hours is 112; it started from the middle of May until the middle of Jun then repeated during almost the whole days of October and September (19 hours in May, 26 hours in Jun, 29 hours in September, 38 hours in October). The average disastrous value is -70% which happened between 14 C and 20 C, especially around 18 C. It is worthwhile to mention most of the bad impacts are in the morning or first hours of operation time (around 8 AM) due to trapped heat releases from inside sources. (Building operation time is between 8 AM until 5 PM during the workdays and 9 AM-4 PM on off days).

At the first step, the dry-bulb temperature (deg C) of the cooling system operation was analyzed. The range of dry-bulb temperature of the operating system in the base model is 15.60 C while the range of the suggested scenario is 18 C. Minimum operating temperature is 16.40 C for the base model but the lowest value of envelope intervention is 14 C; however, the maximum value is the same for both scenarios by 32 C. Therefore the cooling system of the intervention envelop scenario started to work at 14 C whereas the cooling system of the base model started from 16.40 C; in another word, the cooling system of suggesting scenario began to work 2.40 C earlier than the base model. The exact information about the operating temperature of the cooling system is mentioned in Table 5.2 and Figure 5.6 In the following steps, negative impacts were separated from positive values, and a summary of them with relative temperature was mentioned in Table 5.3 values are calculated by using equations 5.1 and 5.4.

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{5.4}$$

$$\text{IQR} = \text{Q1} - \text{Q3}$$

Where s is standard deviation [%], IQR isinterquartile range [%].

Table 5.2: Summarize Dry-bulb Hourly Temperature of Cooling System Operation (deg C).

Variable	n	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	s	IQR
Base Model	1138	16.40	21.20	23.40	23.69	26.27	32.00	3.30	5.07
Envelop Retrofitted	1203	14.00	20.80	23.20	23.36	26.10	32.00	3.50	5.30

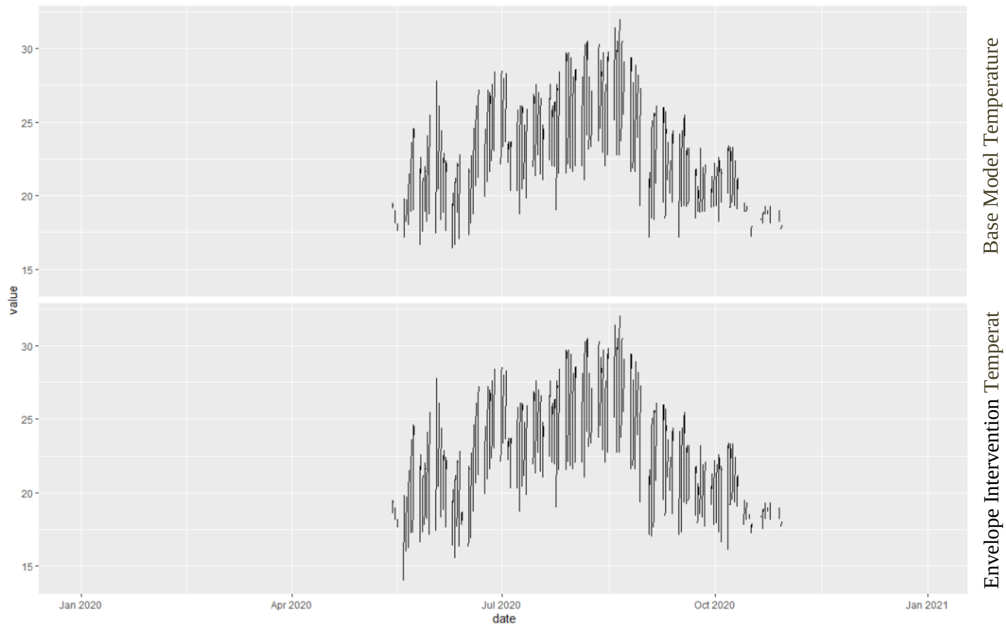


Figure 5.6: Dry-bulb Hourly Temperature of Cooling System Operation (deg C).

Table 5.3: Summarize Operation Temp. and Negative Impact of Cooling systems.

Variable	n	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	s	IQR
Dry-bulb Temp. (C)	112	14.00	17.30	18.10	17.89	18.50	20.10	0.94	1.2
Negative Impact (%)	112	-143.20	-100.00	-100.00	-69.93	-27.77	-0.09	41.82	72.23

5.5 Improvement on Hourly performance of Cooling System

According to the mentioned information, 112 hours of side effects appeared by envelope intervention. Undesirable influences were indicated during the transition months. Shifting the setpoint of the cooling system from 24.5 C to 26 C during specific months, increased the cooling performance without sacrificing comfort that explain in equation 5.5. Changing the setpoint of cooling systems should be done during May, June, September, and October. Modifying the setpoint of the cooling system by 1.5C during the four months could decrease the side effect by 78% which means 112 hours reduced to 24 hours; besides, the performance of ventilation rise by improving cooling performance. A list of final negative impacts is illustrated in Table 5.4.

$$CS = \begin{cases} T_C + 1.5\ C & \text{If May, June, September, October} \\ T_C & \text{Otherwise} \end{cases} \tag{5.5}$$

Where CS is cooling system setpoint (C), TC is based model cooling system temperature (C).

Table 5.4: List of Negative Impact of Envelope Retrofitted on Cooling System after Shifting Setpoint of Cooling System.

Month.Day	Hour	Dry-bulb Temperature (C)	Base Model (Kwh)	Envelop Retrofitted (Kwh)	Negative Impact Rate (%)
5.20	8:00 AM	17.20	0.00	0.34	-100.00
5.27	6:00 AM	17.30	0.00	0.30	-100.00
5.27	7:00 AM	17.50	0.66	0.69	-4.61
5.28	6:00 AM	17.80	0.00	0.71	-100.00
6.10	6:00 AM	15.50	0.00	0.06	-100.00
6.11	6:00 AM	17.70	0.00	0.69	-100.00
6.16	7:00 AM	16.80	0.00	0.08	-100.00
6.17	6:00 AM	16.90	0.00	0.05	-100.00
9.3	6:00 AM	17.00	0.00	0.05	-100.00
9.3	7:00 AM	18.40	0.74	0.80	-7.66
9.9	6:00 AM	18.40	0.96	1.10	-14.49
9.16	6:00 AM	17.30	0.00	0.05	-100.00
9.16	7:00 AM	17.80	0.00	0.46	-100.00
9.23	6:00 AM	17.90	0.00	0.05	-100.00
9.23	7:00 AM	18.10	0.00	0.04	-100.00
9.30	8:00 AM	18.00	0.00	0.38	-100.00
10.6	8:00 AM	17.70	0.00	0.36	-100.00
10.13	8:00 AM	18.20	0.00	0.12	-100.00
10.14	9:00 AM	18.10	0.00	0.18	-100.00
10.15	2:00 PM	18.50	0.00	0.11	-100.00
10.15	3:00 PM	18.50	0.00	0.11	-100.00
10.20	1:00 PM	18.30	0.21	0.24	-14.02
10.20	2:00 PM	18.40	0.23	0.25	-7.50
10.20	3:00 PM	18.40	0.00	0.13	-100.00

6. CONCLUSION AND DISCUSSION

The attention toward the efficient energy building concept is raised during the last years. In this research, an actual educational-office building in the Mediterranean climate was simulated by e-Quest to calculate yearly electric and gas consumption. In the next step, eight scenarios were suggested to identify the energy characteristic of the building and indicate the rate of effect on energy consumption parameters and overall energy performance. Besides, sensitivity analyses were suggested for cost and energy usage. then suggested scenarios divided into two parts that were active strategies and passive strategies.

Appling active strategies are practical ways to convert any existing buildings into zero consumption buildings. Among different strategies for reducing the energy consumption in the building sector, zero consumption buildings have promising potential to reduce energy usage and as well as take advantage of renewable sources. Upgrading lighting systems by replacing lamps and dimming sensors to decrease the electric consumption, applying a solar system to supply the electric consumption, employing a heat pump system to cover gas consumption were considered to reach zero consumption building.

Accordingly, the effective active strategy was the solar system, which included 152 PV panels with 13% efficiency, 4 batteries, and one convertor, by saving 84.75% electric consumption consequently 78.53% primary energy although a little side effect appeared in gas consumption. In the second step, replacing CFL lamps with LED lamps drop electricity usage by 9.58% then by adding dimming sensors promoted to 15.50% whereas 12.39% side effect shown in the gas consumption; however, electricity is more effective than gas usage so the rate of primary energy improvement was 13.47%. The third step was taken by the soil source heat pump which had 4.5 COP; that means using 2370 Kwh/year electric energy to heat the space (requirement energy for space heating was 10,670.72 kWh/year from gas in the base model). The heat pump eliminated the gas consumption of the building and improve primary energy by 5.48%. Therefore, zero energy consumption could be achievable by mentioned methods, which could apply to any kind of building and climate. From the highest to lowest cost-benefit could be a solar system by 84.33%, improving lighting systems by 15.37%, and heat pump save 1.71%. Thus, in the final scenario, 5572$ could be saved in a year which includes 5,545$ electric cost and 27$ gas cost.

Passive strategies have a higher impact on gas consumption rather than electric consumption. To be more precise exterior wall insulation saved gas usage by about 46% that means 4,873.77 kWh/year, roof insulation by 5% which means 550.97 kWh/year, windows replacing 31% which means 3,299.98 kWh/year, and shadow tools by 42% which means 4,437.10 kWh/year reduce gas consumption. The final passive scenario that named envelope retrofitting showed positive performance for not only overall consumptions but also for each consumer parameter. Improving envelop declined the gas consumption by 82% which means 8,768.69 kWh/year and electric consumption by 2% which means 940.00 kWh/year; consequently, 7.5% which means 10,987.09 kWh/year good influenced appeared in the primary energy. The final cost profit is around 111.22 $ in a year.

Passive strategies retrofit the whole building envelope and energy performance of the building. The final passive scenario allocates the energy performance effect of the retrofitting in hourly base to eliminate the negative effects that may not be seen in monthly base evaluation. Accordingly, the energy performance of envelope retrofitting was investigated hourly. The innovation of this study remains on the proposed method that is an hourly investigation to find the side influences and improve them precisely. This method can discover smarter solutions to improve the energy performance better than traditional methods, in other words, this method increases the performance of passive strategies by applying specific solutions based on the present situation rather than relying on a permanent strategy that fits the whole year. Furthermore, hourly analysis of envelope interventions scenario help to identify the building behavior more accurately which will be useful for rising energy performance of the building. The main contributions of this study can be summarized in the following points:

Hourly investigation of envelope retrofitting scenario indicated side effects in some hours for cooling space and ventilation fans. Based on the rate of dependency and data distributions hourly cooling performance should improve. Ventilation fans had an inverse relationship with gas consumption; in this situation, it is optimal to achieve a higher rate of profit by gas consumption (85.31%) with a lower side effect of ventilation fans (-4.23%). Furthermore, Hourly investigation of cooling performance in envelope retrofitting proves the fact that isolation trapped heat inside the building which leads to side effects on cooling systems during the transition months. However, shifting 1.5C setpoint of the cooling system during transition months could compensate for the problem until 78% which means a decline in negative hours from 112 to 24 hours in the comfort zone. Therefore, the rate of improvement energy consumption of cooling system upgrades until 41.44% from 16.16%.

The novelty of this study is filling gaps in sensitivity analysis of energy consumption parameters by not only identifying their effect on overall energy consumption but also identifying their effect on each other. Some interventions may have a positive effect on overall consumption while having a negative effect on each other. Identifying this critical effect in detail not only further improves the energy performance, but also may affect the decision-making of the interventions.

The study can be applied to similar buildings. In future studies integrated more strategies and sensitivity analysis is recommended. Based on the results if strategies apply to diverse buildings with different functions and climates in future works, a huge amount of energy and cost will be saved; consequently, a positive effect appeared for the environment.

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