İZMİR KÂTİP ÇELEBİ ÜNİVERSİTESİ
2010
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

A case study on PV-aided net zero-energy building: the daycare in IKCU

Submitted to the Graduate School of Natural and Applied Sciences
in partial fulfillment of the requirements for the degree of

Master of Science

in Energy Engineering

by
Loic Rebnodji DJANA
ORCID 0009-0001-3958-6884

June, 2023

This is to certify that we have read the thesis **A case study on PV-aided net zero-energy building: the daycare in IKCU** submitted by **Loic Rebnodji DJANA**, and it has been judged to be successful, in scope and in quality, at the defense exam and accepted by our jury as a MASTER'S THESIS.

APPROVED BY:

Advisor: **Asst. Prof. Sahin Gungor**
İzmir Kâtip Çelebi University

Committee Members:

Assoc. Prof. Ziya Haktan KARADENİZ
İzmir Institute of Technology

Assoc. Prof. Erman ÜLKER
İzmir Kâtip Çelebi University

Asst. Prof. Sahin GUNGOR
İzmir Kâtip Çelebi University

Date of Defense: June 20, 2023

Declaration of Authorship

I, **Loic Rebnodji DJANA**, declare that this thesis titled **A case study on PV-aided net zero-energy building: the daycare in IKCU** and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for the Master's / Doctoral degree at this university.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this university or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. This thesis is entirely my own work, with the exception of such quotations.
- I have acknowledged all major sources of assistance.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Date: 20.06.2023

A case study on PV-aided net zero-energy building: the daycare in IKCU

Abstract

At the core of our growing societies, energy supply stands as one of the major concerns today, and it will be an inevitable challenge for our near future. As the nations are looking to find solutions for the transition from fossil fuels – depleting at a high rate – to alternative energy sources, solar energy through PV cells is getting attention as an affordable and easily implemented option especially for power supply in commercial and residential buildings. This work consists in analyzing the possibility to cover the entire energy needs of a building via PV solar cells for the case of a constructed daycare. In this case study, HVAC energy requirement has been calculated by the TS825 standard. The standard specifies a method for calculating the net heating/ventilation energy need and provides the rules for calculating the maximum allowable temperature in buildings. First, dimensions of the investigated building are taken and characteristics affecting the thermal insulation are assessed. Then, other energy needs, mainly lighting and electrical devices, are computed in the analysis as internal electricity needs. The scope of this work extends to the assessment of indoor air quality for occupants of building, which is an important aspect in our case study where the occupants are children. ASHRAE standards 62.1 is utilized for this purpose. The standard specifies minimum ventilation rates and other measures intended to provide acceptable indoor air quality to human occupants and that minimizes adverse health effects. The results are obtained for monthly varying solar exposition in the specified area where the building is located to provide supply for the determined energy demand via solar energy. Finally, monocrystalline PV panel system has been proposed with proper orientation and adequate power potential. Based on the obtained results, as well as the economical aspect, inferences and suggestions are made for improvement.

Keywords: Zero-energy building, energy consumption, power generation, photovoltaic (PV) panels, Heating, ventilation, air conditioning, and refrigeration (HVAC-R) units, Turkish Standard TS825

PV destekli net sıfır enerjili bina üzerine bir araştırma: İKÇÜ kreş binası

Öz

Büyüyen toplumlarımızın merkezinde yer alan enerji arzı, günümüzün en önemli sorunlarından biridir ve yakın geleceğimiz için de kaçınılmaz bir sorun olacaktır. Ülkeler yüksek oranda tükenmekte olan fosil yakıtlardan alternatif enerji kaynaklarına geçiş için çözümler ararken, PV hücreleri aracılığıyla güneş enerjisi, özellikle ticari ve konut binalarında güç kaynağı için uygun fiyatlı ve kolay uygulanabilir bir seçenek olarak dikkat çekmektedir. Bu çalışma, inşa edilen bir kreş örneğinde, bir binanın tüm enerji ihtiyacının PV güneş pilleri aracılığıyla karşılanma olasılığını analiz etmeyi içermektedir. Bu örnek çalışmada, HVAC enerji gereksinimi TS825 standardına göre hesaplanmıştır. Standart, net ısıtma/havalandırma enerjisi ihtiyacının hesaplanması için bir yöntem belirlemekte ve binalarda izin verilen maksimum sıcaklığın hesaplanması için kurallar sunmaktadır. İlk olarak, incelenen binanın boyutları alınır ve ısı yalıtımını etkileyen özellikler değerlendirilir. Daha sonra, başta aydınlatma ve elektrikli cihazlar olmak üzere diğer enerji ihtiyaçları analizde dahili elektrik ihtiyacı olarak hesaplanır. Bu çalışmanın kapsamı, bina sakinleri için iç hava kalitesinin değerlendirilmesine kadar uzanmaktadır ki bu, bina sakinlerinin çocuk olduğu vaka çalışmamızda önemli bir husustur. Bu amaçla ASHRAE standartları 62.1 kullanılmıştır. Standart, bina sakinlerine kabul edilebilir iç mekan hava kalitesi sağlamayı amaçlayan ve olumsuz sağlık etkilerini en aza indiren minimum havalandırma oranlarını ve diğer önlemleri belirtir. Sonuçlar, belirlenen enerji talebinin güneş enerjisi ile karşılanması için binanın bulunduğu bölgede aylık olarak değişen güneş maruziyeti için elde edilmiştir. Son olarak, uygun yönlendirme ve yeterli güç potansiyeline sahip monokristal PV panel sistemi önerilmiştir. Elde edilen sonuçlara ve ekonomik boyuta dayanarak, iyileştirme için çıkarımlar ve öneriler yapılmıştır.

Anahtar Kelimeler: Sıfır enerjili bina, enerji tüketimi, enerji üretimi, fotovoltaik (PV) paneller, Isıtma, havalandırma, iklimlendirme ve soğutma (HVAC-R) üniteleri, Türk Standardı TS825

This research paper is dedicated to the DJANA family for their unconditional support, and to all contributors: mentors, friends, and family, who have directly or indirectly made this work possible;

gratitude and glory to God

Acknowledgment

First and foremost, I would like to express my deepest appreciation and gratitude to my advisor, Asst. Prof. Sahin Gungor for his valuable mentorship and patience throughout every step of this work. I am also thankful to my fellow colleagues Ilkin Arda Gurel and his group, as well as Veli Sabanci and his group for their collaboration and contribution. Needless to say, special thanks go to the Graduate School of Natural and Applied Sciences staff, under the direction of Prof. Dr. Mehmet CEVIK who has played an important role in facilitating the completion of my Master of Science program. Likewise, my appreciation goes to the head of the Energy Engineering department: Assoc. Dr. Erman Ülker, and to all the professors of the Energy Engineering program as well as Izmir Katip Celebi staff for their guidance and cooperation. I’m extremely grateful to my parents Simeon and Therese DJANA who have made possible my education in Turkey, and who always supported and motivated me do my best. I would like to extend my sincere thanks to my respectable friends Youssouf Camara, Shaymah Awwal Nunnoo, Mamar Ali Sirfi, Dilfuza Zahid and Rania Tatlidede for the very appreciated support and encouragement towards me during my education and the preparation of this thesis. This endeavor would not have been possible without them all. Lastly and above all, I thank God Almighty for his grace expressed through the achievement of this work.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CBE	Center for Built Environment
COP	Coefficient of Performance
HVAC	Heating, Ventilation, and Air Conditioning
HRV	Heat Recovery Ventilation
İKÇÜ	İzmir Kâtip Çelebi University
NZEB	Net Zero Energy Building
PMV	Predicted Mean Vote
PV	Photovoltaic
ROI	Return On Investment
TRY	Turkish lira
TS	Turkish Standard
ZEB	Zero Energy Building

List of Symbols

ρ	density of air (kg/m^3)
β	The rate of time the fans are running
μ	Water vapor diffusion resistance coefficient
φ	Relative humidity
η	Efficiency, gain utilization factor
λ_h	Thermal conductivity calculation value (W/m.K)
$\Phi_{s,\ month}$	Average monthly solar gain (W)
$\Phi_{i,\ month}$	Monthly average internal heat gain (W)
η_v	Efficiency of air-to-air heat recovery system
1/U	Total thermal permeability resistance of the building component (m^2.K/W)
R	Thermal permeability resistance (m^2.K/W)
R_e	External surface thermal conduction resistance (external heat (m^2.K/W) transfer coefficient) (m^2.K/W)
R_i	Inner surface thermal conduction resistance (inner surface heat convection coefficient) (m^2.K/W)
A	Total area of building elements (m^2)
A_D	Outer wall area (m^2)
Ad	Area of floor/floor in contact with outside air (m^2)
A_{dsic}	Area of building elements in contact with indoor environments at low temperatures, (m^2)
A_i	total window area in the i direction (m^2)
A_n	building usage area (m^2)
A_p	window area (m^2)
A_T	ceiling area (m^2)
A_t	Floor-to-floor/floor area (m^2)

A_{total}	The total area of the building's heat-losing surfaces (m^2)
c	specific heat of air (J/kgK)
d	Thickness of the building component (m)
e	The building condition coefficient to be used in the mechanical ventilation calculation
f	Surface coefficient to be used in mechanical ventilation calculation
$g_{\perp}$	Solar energy transmission factor measured under laboratory conditions for a beam perpendicular to the surface
$g_{i,\ month}$	Solar transmission factor of transparent elements in the i direction
H	Specific heat loss of the building (W/K)
H_v	Heat loss through ventilation (W/K)
H_T	Heat loss by conduction and convection (W/K)
$\dot{I}$	Diffusion flow density (kg/m^2h)
$I_{i,\ month}$	Monthly average solar radiation intensity on vertical surfaces in the i direction (W/m^2)
KKO_{month}	win / loss ratio
n_{50}	Air exchange rate when there is a pressure difference of 50 Pa between indoor and outdoor environments
n_h	air exchange rate (h^{-1})
P	Partial water vapor pressure (Pa)
P_d	The water vapor partial pressure of the air in contact with the outer surface of the building component (Pa)
P_i	The water vapor partial pressure of the air in contact with the surface of the building component in the room (Pa)
P_s	Saturated water vapor pressure at temperature T (Pa)
P_{sw}	Saturated water vapor pressure (Pa)
q	heat flux density (W/m^2)
Q_{month}	Monthly heating energy requirement (Joule)
Q_{year}	Annual heating energy need (Joule)
$r_{i,month}$	Monthly average shading factor of transparent surfaces in the i direction
t	Time (a month in seconds 86400 x 30) (s)
θ_e	Monthly average outdoor temperature (°C)

θ_i	Monthly average indoor temperature (°C)
θ_{yd}	External surface temperature (°C)
θ_{yl}	Internal surface temperature (°C)
$\theta_{yl,\ lowest}$	Lowest acceptable internal surface temperature (°C)
U	Coefficient of thermal conductivity of the building component (W/m^2K)
U_d	Coefficient of thermal conductivity of the base in contact with the outside air (W/m^2K)
U_D	Coefficient of thermal conductivity of the external wall (W/m^2K)
U_{dsic}	Coefficient of thermal conductivity of structural elements in contact with indoor environments at low temperatures (W/m^2K)
U_p	Coefficient of thermal transmittance of the window (W/m^2K)
U_T	Coefficient of thermal conductivity of the ceiling (W/m^2K)
U_t	Thermal conductivity coefficient of the base/slab resting on the ground (W/m^2K)
V_0	Air exchange flow rate by volume when ventilators are not operating (m^3/h)
V_{gross}	Gross heated volume of the building (m^3)
V_E	Air outlet flow rate (m^3/h)
V_f	Average air exchange flow rate by volume in ventilators (m^3/h)
V_h	Ventilated volume (m^3)
V^1	Total air exchange flow rate by volume (m^3/h)
V_S	Fresh air inlet flow rate (m^3/h)
g	Amount of water vapor per unit area (kg/m^2s)
S_d	Water vapor diffusion-equivalent air layer thickness
δ_p	Water vapor permeability of the material depending on the partial vapor pressure (kg/ms Pa)
δ_o	Water vapor permeability of air depending on partial vapor pressure (kg/ms Pa)
ν	Moisture content per unit volume of air (kg/m^3)
Δ_v	Excess humidity of the indoor environment, v_i - v_e (kg/m^3)
Δ_p	Vapor pressure excess of the indoor environment, P_i - P_d (Pa)

Chapter 1

Introduction

As the world population continues growing, energy demand due to industrial and human-based activities increases in parallel. The International Energy Agency's (IEA) World Energy Outlook 2020 report [1] examined the future of the global energy sector. It exhibits the connection between population growth, energy demand, and greenhouse gas emissions. The report recognizes that as the world's population continues to rise, so does the demand for energy-intensive activities. As fossil fuels remain the greatest source for energy generation worldwide, the report highlights the urgent need for a shift towards renewable energy sources as a solution to mitigate pollution and shortage in resources, which are the main problems associated with dependence on fossil fuels. The report emphasizes that renewable energy technologies offer a viable and attractive alternative to conventional energy sources, providing a sustainable pathway to meet the world's energy needs while reducing environmental impacts. Usage of renewable energy sources has become an attractive alternative to conventional energy sources to meet the growing energy demand while reducing greenhouse gas emissions.

The International Renewable Energy Agency (IRENA) perfectly illustrate this fact in their article "Renewable power generation costs in 2020"[2]. Their investigation provides insights on the cost competitiveness of renewable energy. It highlights how renewable power generation costs have declined significantly in recent years, making them increasingly appealing compared to conventional energy sources. This cost reduction, combined with advancements in technology, enables the utilization of renewable energy sources to meet the growing energy demand while simultaneously reducing greenhouse gas emissions. One of the most promising renewable energy sources today is solar or radiant energy which can be harvested via photovoltaic (PV) panels. Dr. A. K. Pandey et al. [3] provided in their work a valuable perspective on this subject. In their paper on the ‘’Recent advances in solar photovoltaic systems for emerging trends and advanced applications’’, first they demonstrate the increasing demand for energy globally due to industrialization, population growth, and improving living standards, this confirms the findings from IEA and ARENA reports previously mentioned. Then, their article emphasizes that the use of traditional energy sources, especially in rural areas of developing countries, is unsustainable and leads to deforestation and pollution. They further state that fossil fuels, the major driver of the world economy, contribute to environmental pollution. Thus, there is an urgent need to explore renewable energy sources that can meet growing energy requirements while being environmentally friendly. They specifically mention solar energy as one of the promising renewable energy sources. The article shows how solar energy, along with other renewable sources such as wind, bioenergy, geothermal, and small hydro, possesses the qualities required for meeting present and future energy needs. Although renewable energy sources face challenges such as low efficiency, high capital costs, and unequal availability, scientists and engineers worldwide are continuously making efforts to overcome these issues. Solar photovoltaic (PV) systems are highlighted as an important component of the renewable energy mix. They are described as rugged, simple in design, and capable of generating power from microwatts to megawatts. Solar PV systems have proven their efficiency in numerous situations like for example in electrifying rural areas in developing countries. The remarkable growth in worldwide solar energy generation is illustrated in Figure 1.1.

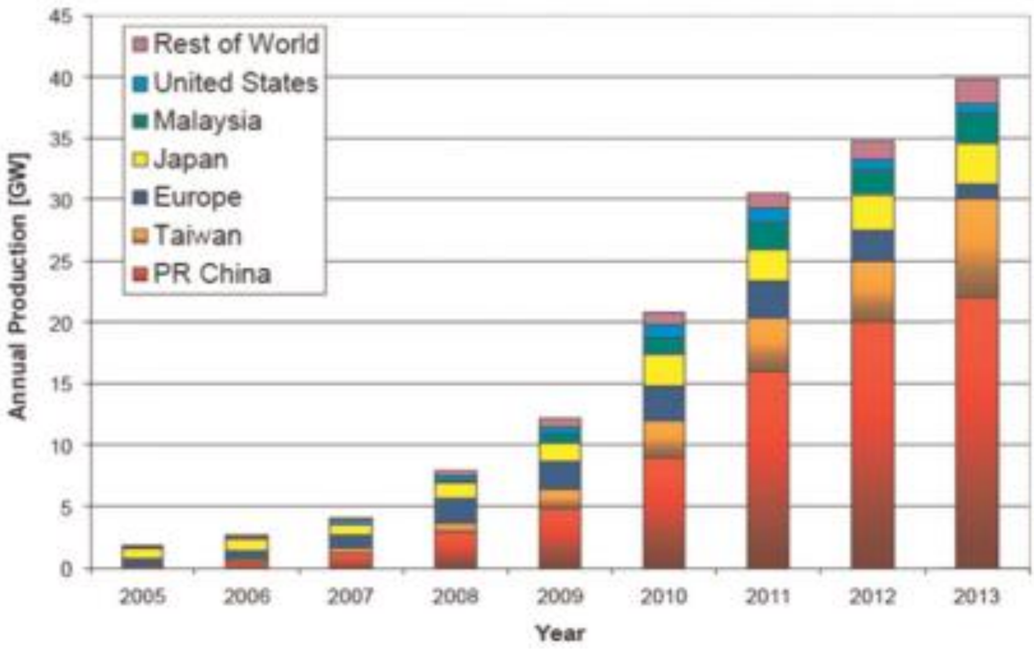

Figure 1.1: World PV cell/module production from 2005 to 2013 [4].

The recent progress in efficiency of PV panels [5] has allowed the rise of concepts like zero and net-zero energy buildings.

A zero-energy building (ZEB) is a construction that generates adequate energy for annual energy consumption, from renewable energy sources. Such buildings are designed to reduce energy consumption to a minimum and produce the remaining energy using renewable sources. The concept of zero energy buildings has gained increasing popularity due to the growing concerns on sustainable environment and energy-efficient buildings. To better understand the concept, a research paper on the background history and evolution of ZEBs, by Jaysawal RK et al. [6] represents a very useful resource. In his article, Jaysawal defines the term ZEB as a building that exhibit zero net energy consumption, wherein the total energy used annually is approximately equal to the total sum of renewable energy produced on-site. He explains that the idea of ZEBs emerged in the late 1970s and early 1980s when phrases like "zero energy home" or "energy-independent house" were used. However, the lack of a common understanding of ZEBs has led to variations in its definition. Some key definitions include:

- qbal (2004): A building that incorporates commercially available renewable energy technologies and energy-efficient construction methods while avoiding the use of fossil fuels. [7]

- Kilkis (2007): A building that has zero energy transfer through all electric and other transfers occurring during a specific time span. [8]

- Laustsen (2008): Zero-energy buildings that rely entirely on solar and other renewable energy sources, eliminating the use of fossil fuels. [9]

- Noguchi et al. (2008): Houses that consume as much energy as they produce over a certain period of time. [10]

These definitions highlight the emphasis on renewable energy integration, energy efficiency, and the absence of fossil fuel consumption in ZEBs. He further defines the concept of Net Zero Energy Building (NZEB), as a building, following the principles of ZEBs, that aims to achieve a balance between the energy consumed and the energy produced from renewable sources. The term "net zero" refers to the balance between the amount of greenhouse gas emissions produced and the amount removed from the atmosphere. NZEBs have gained popularity in recent years, with the global market for NZEB construction and renovation expected to surpass $1.4 trillion by 2035.

As the research suggest: ZEBs and NZEBs can generate on-site the energy they consume, using renewable energy sources. Pless and Torcellini [11] in 2007, presented a comprehensive classification system for net zero energy buildings (NZEBs) based on different renewable energy supply options. The research objectives included developing a framework to categorize NZEBs, examining the feasibility of achieving net zero energy performance, and assessing the comparative effectiveness of various renewable energy supply options. The study incorporates a combination of theoretical analysis and case studies to fulfill these objectives. The authors developed a classification system based on the source of renewable energy used in NZEBs. They categorize NZEBs into four classes: net zero site energy, net zero source energy, net zero energy costs, and net zero emissions. The authors then analyze the effectiveness of various renewable energy supply options, such as solar photovoltaic (PV) systems, wind turbines, biomass, and geothermal energy, within each classification. In their results, the authors highlight the significant role of solar PV systems due to their high energy generation potential and compatibility with various building types. However, the authors emphasize the importance of considering the context-specific factors such as available resources, climate, and building energy demands when selecting the optimal renewable energy supply option for NZEBs. As their performance in ZEB et NZEB installations was exhibited, PV-panel systems have become commonly used in zero energy buildings to generate renewable energy-based electricity. PV panels convert sunlight into electricity without any harmful emissions. The size and capacity of the PV systems depend on the building's energy demand and the available solar irradiation. PV-aided zero energy buildings have been researched extensively in recent years. The paper by Charron, R. [12], provides a comprehensive review of low and net-zero energy solar home initiatives. His research aims to analyze the various initiatives undertaken to promote low and net-zero energy solar homes, identify their objectives, outline the steps involved, and present the key results achieved. By examining these initiatives, the study seeks to gain insights into the effectiveness of different strategies in achieving low and net-zero energy performance in residential buildings. He defines net-zero energy solar homes as buildings that use solar thermal and solar PV technologies to generate as much energy as their annual load. His aims in this work are consist in reducing energy consumption, integrating renewable energy sources, improving energy efficiency, and promoting sustainable building practices. The study outlines the steps taken by the initiatives to achieve low and net-zero energy performance in residential buildings. These steps may include designing energy-efficient building envelopes, incorporating solar PV systems, implementing energy management systems, optimizing HVAC systems, and adopting energy-efficient appliances. The key results of his work can be listed as follows:

- The initiatives have successfully demonstrated the feasibility of achieving low and net-zero energy performance in residential buildings.

- Integration of solar PV systems plays a crucial role in achieving energy self-sufficiency and reducing reliance on traditional energy sources.

- Energy-efficient building design, including effective insulation, high-performance windows, and advanced HVAC systems, significantly contributes to energy savings.

- Homeowner engagement and awareness campaigns are vital for the success and widespread adoption of low and net-zero energy initiatives.

- Collaboration among stakeholders, including government agencies, industry professionals, and homeowners, is essential for the effective implementation of these initiatives.

These encouraging results have played in important role in the development of ZEB and NZEB, opening a pathway to follow and giving inspiration for future projects.

In western countries, around 30% of the total energy consumption is attributed the energy used in buildings, as described by González-Torres M et al [13]. Their research points out the factors causing this growth in the building energy consumption, and highlights the massive portion attributed to HVAC-R systems as 38% of the total building consumption. The author warns about this dangerous growth in building energy consumption which is on the front scene of climate policies concerns. She explains the importance of reducing this consumption and implementing more efficient and eco-friendly energy management system. Her studies confirm the idea that the main factor affecting the total energy demand in buildings is the heating, ventilation, air conditioning and refrigeration (HVAC-R) units.

This fact is better illustrated in Figure. 1.2 by a pie chart from the National Academies of Sciences of the US [14].

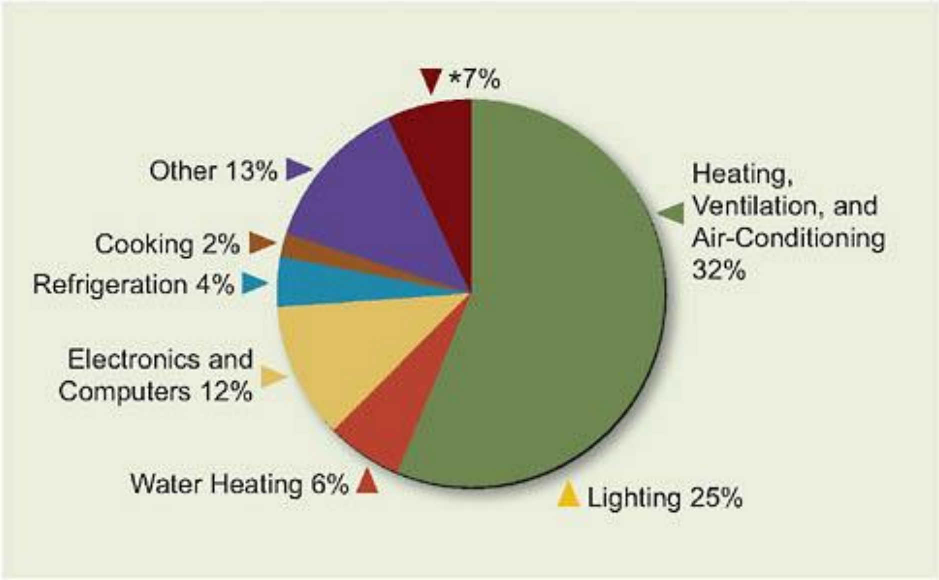

Figure 1.2: Energy use in U.S. commercial buildings [14]

A review of energy consumption by Fajardy M, Reiner DM (2020) documented that space heating accounted for the largest proportion of energy consumption in both residential and commercial buildings The authors note that this is due to a combination of factors, including the climate conditions and building design.

The paper by Fajardy and Reiner (2020) [15] provides an overview of the electrification of residential and commercial heating and cooling systems and discusses the prospects for decarbonization. The authors examine the role of heating, ventilation, air conditioning, and refrigeration (HVAC-R) systems in total energy demand in buildings, particularly in western countries. They highlight that HVAC-R systems are a primary factor influencing the total energy demand in buildings. The paper addresses the challenges and opportunities of electrifying these systems to reduce carbon emissions and achieve decarbonization goals. It discusses various technologies and policy consideration for transitioning to electrified heating and cooling systems in both residential and commercial sectors. The paper contributes to the understanding of the importance and impact of HVAC-R systems in building

energy demand and explores the potential for decarbonization through electrification.

The methods for evaluating the energy performance of low-energy buildings can be categorized into three primary types:

- Simplified or Steady-State Methods [16]: This category includes the Quasi-Steady-State Calculation Method. These methods are based on simple equations and steady-state assumptions, such as constant temperature conditions and solar gains, and are often used for preliminary design or compliance checking.

- Detailed or Dynamic Simulation Methods [17]: This includes methods like the Dynamic Simulation Method and EnergyPlus. These methods offer more accurate and detailed analysis of the thermal behavior of a building by considering the dynamic interactions between different factors such as time-varying weather conditions, occupancy, and system operations.

- Data-Driven or Machine Learning Methods [18]: These methods, including Artificial Neural Networks (ANN), use machine learning algorithms to learn patterns in historical data, and can be used to predict future building energy performance. These methods are especially useful when large amounts of data are available.

While the Dynamic Simulation and the Data-Driven methods might offer appropriate analysis for buildings with complex designs and systems, or for evaluating specific dynamic behaviors such as peak loads or thermal comfort over time, Steady-State methods have the advantages of

1. Simplicity: These methods use simplified assumptions and equations which make them easy to use and understand. They do not require a detailed understanding of thermodynamics or complex software.

2. Speed: Because of their simplicity, these methods can quickly provide an estimate of a building's energy performance. This makes them ideal for preliminary design stages or for checking compliance with building regulations.

3. Lower computational requirements: Unlike detailed simulation methods, quasi-steady-state methods do not require high computational power or complex software, making them more accessible to use.

4. Useful for initial design decisions: These methods can provide valuable insights into the potential energy performance of a building design, and can be used to inform initial design decisions.

5. Broad applicability: Since these methods are based on generalized assumptions, they can be applied to a wide variety of building types and climates.

Our preference in this research, went for the Turkish Standard TS825. This technical norm developed by the Turkish Standards Institution (TSE), provides a guideline for the calculation of energy requirement in the residential/commercial buildings. Besides benefiting from all the advantages of the Quasi-steady-state methods mentioned above, it is also specially designed to serve in Turkey for local buildings. The title of the standard is "Energy Performance of Buildings - Calculation of Energy Use for Heating and Cooling. [19]. In Turkiye, it is estimated that buildings that obey the TS825 regulations for insulation can save up to 60% of the energy used for heating purpose. As energy represents a major issue today in the world and especially in the country, TS825 has become a mandatory norm for all new buildings as of 14th June 2000. The purpose of TS825 is to provide a standardized method for assessing the energy performance of buildings, particularly with respect to heating, heat gains and heat losses. The standard allows engineers and designers to determine the energy performance of buildings using a range of parameters, including the building placement, wall specifications, ceiling layers, floor type and layers, window types and area, door type, indoor and outdoor temperature level for each month, heating and cooling systems, ventilation system and type, and solar heat gains. We mainly utilized from this standard and the methodology within it to determine the monthly and annual heating energy requirement for the building considered in our case study, i.e., the daycare (nursery) at Izmir Katip Celebi University. In that calculation method, TS825 mainly takes into consideration: building properties such as construction materials, heat losses through conduction convection and ventilation; as well as heat gains from internal sources and solar radiation, to determine the heating energy need for the building. Besides these parameters, insulation is another important factor considered in the TS825 calculation method like in most energy assessment methods for buildings, as it can have significant effect on the heat loss of the building and thus, affect the energy demand [20]. In their review paper on insulation materials, Aditya, Lisa, et al. [21] investigate the impact of insulation on heat gain and heat loss, it discusses the role of insulation in reducing heat transfer improving thermal comfort, and minimizing energy consumption in buildings. The article examines various types of insulation materials and their thermal properties. It also discusses the impact of insulation on reducing greenhouse gas emissions and achieving sustainability goals. The review highlights the significance of proper insulation design, installation, and maintenance for maximizing energy efficiency in buildings. Their work represents a valuable material to refer to when assessing energy systems in buildings.

Other factors considered when calculating the energy need in our work are the energy needs for cooking, lighting, refrigeration, electronic devices, and water heating. Their values are relatively constant, and they are taken as monthly and yearly average. The calculation provides an accurate estimation of the total energy demand of the building. The procedure is detailed in section 2.

ZEBs sound very promising at first glance, but after close to twenty years of research and development, the number of such buildings is still very low. The World Green Building Council (WorldGBC) [22] estimates not more than 500 net zero commercial buildings and 2,000 net zero homes on the whole planet, which represents way lesser than 1% of the total buildings, implying that the implementation of such projects is not as simple as it may sound. In his evaluation of the pros and cons of renewable energy use for power generation, Maradin Dario [23] gives an insight of the possible limitations one may face when trying to use PV-panel to achieve ZEBs. The author discusses the disadvantages and limitations of using renewable energy sources, with a focus on solar energy and wind energy. One of the main challenges is the dependency on geographical location and weather conditions, which leads to the volatility and unpredictability of renewable sources. This poses a significant limitation in electricity generation and can be mitigated through careful site selection and planning. The large daily oscillations in the availability of these sources can also pose a problem and necessitate the consideration of integrating renewable electricity into the existing grid as possible solution, which in a manner may contradict the very idea of ZEBs. In terms of capacity, renewable energy sources, including solar energy, have lower capacity compared to fossil fuel. To address this, further investment in renewable energy technologies and the construction of more renewable energy plants are needed. Additionally, renewable energy systems and plants require a larger area compared to thermal power plants to produce the same amount of electricity. The energy efficiency of renewable sources, except for hydropower and wind farms, is relatively lower. For example, photovoltaic and geothermal power plants have the lowest energy efficiency. Renewable energy sources also have shorter operating periods at full power compared to fossil fuel power plants. On average, renewable energy sources like wind and solar operate at maximum power for about 2000 hours per year, while coal, gas, and nuclear power plants can operate up to 7500 hours per year. This indicates the need for careful consideration of the capacity factor, especially when thinking of providing the whole energy demand from these intermittent sources. His research also mentions the significant challenge represented by the relatively high cost of electricity production from renewable sources compared to fossil fuel plants. However, when considering the ecological component of electricity production and the cost of carbon dioxide emissions, renewable energy sources become more competitive with fossil fuel plants.

The wellbeing of occupants in a Net Zero Energy Building (NZEB) is another factor of major importance that should be considered preferably from the design stages for new buildings, or alternatively during the settling of the system for old buildings. NZEBs are designed not only to minimize energy consumption and reduce carbon emissions, but also to foster a healthier and more comfortable living environment for its inhabitants. A quality environment often translates into improved physical and psychological wellbeing of occupants. Zeiler W. [24] highlighted this aspect in his research paper on Net Zero Energy Buildings drawbacks, placing individual human comfort as a leading objective in his work. A building that achieves energy efficiency but fails to provide a healthy, comfortable environment for its inhabitants would not be deemed successful, especially in this case study, where the investigated building is a daycare with infant population. Therefore, the focus on occupants’ wellbeing is necessary from the design to the implementation and the assessment approaches in NZEBs.

To sum it up, research has demonstrated that zero and net zero energy buildings, which are still in their early ages, have the potential to become our best solution towards universal net zero carbon in the building sector and contribute strongly in healing our planet from pollution and global warming. Nevertheless, while renewable energy sources offer numerous advantages, including environmental sustainability and additional energy forms, there are challenges and drawbacks that still need to be addressed in order to achieve their effective implementation.

In our case study, we investigate usage of PV panels for the daycare building at Izmir Katip Celebi University to cover all the energy requirement in an annual period. Our assumption in this work is that under the specified conditions, PV-panels will provide 100% of the energy needs for the daycare in our case study, making it a net zero-energy building.

First, the monthly and annual heating energy loads of the selected nursery are calculated via TS825 standard. Next, energy consumption due to the electronic appliances, lighting and specific devices are determined to obtain total energy requirement of the investigated building. PV panel type and total number of PV panels have been determined according to the maximum energy requirement case experienced in January.

Indoor air quality and personal comfort conditions have been considered while calculating the total energy consumption of the investigated domain. ASHRAE 62.1 standard [25] is used for ventilation rates and indoor air quality requirements. This standard provides guidelines for the assessment of indoor air quality of occupants in various spaces. In a daycare, where the occupants are kids/children, this standard is crucial in achieving a viable zero energy building and ensuring the health and safety of kids. To the same extend, ASHRAE 55 is utilized for the determination of personal comfort conditions especially for the ventilation speed point of view [26]. By incorporating these standards in the analysis, we can leverage their guidelines and recommendations to assess and improve indoor environment for human activities.

Furthermore, a detailed cost analysis has been performed to compare the investment cost of possible PV solutions.

Chapter 2

Methodology

Our work can be presented chronologically in the following main steps:

- determination of the total energy needs of the building,
- investigation on PV-panels to cover the energy demand,
- evaluation of insulation effect,
- evaluation of occupant’s comfort,
- cost analysis of the project.

Several methods can be considered when dealing with energy assessment and energy generation in buildings. The methodology followed at the first stage was initially inspired by the TS825 standard and adjusted to fit our study-case, then in the following stages, a suitable and verifiable method is provided in view of achieving the objectives. This section describes these methods and how they were used in our approach at each step for the implementation of the project.

2.1 Calculation of the building total energy demand

2.1.1 Building properties

The investigated building is presented in Figures 2.1 and 2.2.

Figure 2.1: IKCU daycare building (front view)


Figure 2.2: Technical drawing representation of the daycare (top view)

The first step in our work is to measure the building properties needed at all calculation stages of the TS825. They include mainly: measurements of dimensions, heat losing surfaces, area of each component considered in calculations, and total window and door areas in each direction. The data are presented in Table 2.1.

Table 2.1 Main dimensions and specifications of the investigated building.

Building dimensions (m)		Layer/wall areas (m^2)		Gross volume (m^3)	Window area (m^2)		Door area (m^2)		Internal Temp. (ºC)
Length	18,9	Reinforced Concrete	53,4	1791	North	20,6	North	0	20
Width	25,5	External Wall	202,5		East	16,3	East	5,9	
Height	3,7	Ceiling	484,1		West	13,0	West	0	
Floor Height	3	Floor	484,2		South	15,6	South	1,9	
		Total Area	1297,6		Total	65,5	Total	7,9	
		Net Usage	573,3						

2.1.2 Heating energy need

The heating energy need for the building, as stated in the previous sections, is the main factor affecting the total energy demand. That value was calculated according to the systematic calculation method using the TS825 with the data listed in Table 2.1. The calculation steps contain: calculation of heat loss of the building (through conduction, convection), calculation of heat gain of the building (internal and solar gains), and lastly, calculation of the heating energy need using the obtained data.

2.1.2.1 Heat loss of the building

In order to determine the specific heat loss of the building, we initially focused on the heat loss through conduction and convection. Then we calculate the heat loss through ventilation, and we add the two values to get the total heat loss value as shown in Eq. (1).

$$H = H_T + H_V \tag{1}$$

where, H is the total specific heat loss, H_T is the heat loss through conduction and convection heat transfer mechanisms, and H_V denotes the heat loss through ventilation. First, we calculate the thermal permeability resistance (R) values of each building components via Eq. (2) to determine H_T.

$$R = \frac{d}{\lambda} \tag{2}$$

where, R corresponds to the thermal permeability resistance (m^2K/W), d is the thickness of the building component, and λ is the thermal conductivity of the components (W/mK). Note that the thermal conductivity values are provided in Annex E of the TS825 [19]. R-value calculation for multi-layered building components is made by simply adding the R-values of each structural element (layer) of the component. Utilizing the R-values previously calculated, we derive the total thermal performance coefficient (U), from the inverse function of total thermal permeability resistance (1/U) formula, for each component, as shown Eqs. (3) and (4).

$$\frac{1}{\mathrm{U}} = R_i + \mathrm{R} + R_e \tag{3}$$

$$\mathrm{U} = \frac{1}{R_i + \mathrm{R} + R_e} \tag{4}$$

In equations (3) and (4), R_i and R_e are the surface thermal transmission resistance of the inner and outer surfaces, respectively. R_i and R_e values are provided in TS825 standard for various building scenarios. The heat loss by conduction and convection

H_T value is then calculated by summing up the products of each component's total thermal performance coefficient (U) by its specific area (A), and adding to it the heat loss transmitted through the thermal bridges, as shown in equation (5).

$$H_T = \sum \mathrm{AU} + \sum \mathrm{Ul} \quad (5)$$

In the case of our building that doesn't contain thermal bridges, the term ($\sum$Ul) is ignored from equation (5) which can then be developed for each component, giving us equation (6).

$$\sum \mathrm{AU} = U_D A_D + U_p A_p + U_k A_k + 0.8\, U_T A_T + 0.5\, U_t A_t + U_d A_d + 0.5 U_{ds} A_{ds} \quad (6)$$

where:

U_D = Thermal permeability coefficient of the outer wall (W/m^{2}K),
U_P = The thermal transmittance coefficient of the window (W/ m^{2}K),
U_k = Thermal permeability coefficient of the outer door (W/ m^{2}K),
U_T = Thermal permeability coefficient of the ceiling (W m^{2}K),
U_t = Thermal permeability coefficient of the base/floor on the ground (W/ m^{2}K),
U_d = Thermal permeability coefficient of the sole in contact with the outside air
U_{ds} = The coefficient of thermal permeability of the building elements in contact with the indoor environments at low temperatures (m^{2}K),
A_D = Area of the outer wall (m^2),
A_P = Area of the window (m^2),
A_k = The area of the outer door (m^2),
A_T = Ceiling area (m^2),
A_t = Floor-to-floor/floor area (m^2),
A_d = Area of floor/floor in contact with outside air (m^2),
A_{ds} = Area of building elements in contact with indoor environments at low temperatures (m^2).

The calculation of heat loss by ventilation, H_V includes both natural and mechanical ventilations affecting to the building. In the case of the daycare building of our study, since there is no mechanical ventilation, only natural ventilation is considered and calculated as follows:

$$H_V = \rho . c . V^1 = \rho . c . n_h V_h = 0.33\, n_h . V_h \quad (7)$$

where, ρ is the unit volume mass of air, c is the specific heat capacity, V^1 corresponds to air exchange rate by volume, n_h is the air exchange rate, and V_h denotes the ventilated volume. The coefficient of 0.33 results from the multiplication of the air density ρ and the specific heat capacity of air c. Therefore, it represents the thermal energy losses per unit volume (m^3) and per temperature difference (J/m^3K).

As density and specific heat capacity of the air slightly changes (depending on temperature and pressure), their variations are neglected in the equation, and values are taken at 20 °C and 100 kPa. The enthalpy increase between the incoming and outgoing air is also neglected.

2.1.2.2 Heat gains

Heat gains need to be calculated to determine the monthly and annual energy demand of the building. Heat gain term refers to the amount of heat that enters the building through various sources such as solar radiation, appliances, lighting, and occupants. In this study, we calculate total heat gains as the sum of internal and solar gains. Average monthly internal heat gains ($\phi_{i,\ month}$) include metabolic heat gains from humans, heat gains from the hot water system, heat gains from cooking, heat gains caused by the lighting system, heat gains from various electrical devices used in buildings. These values are taken as the average and considered constant throughout the year. For our building category (school), internal heat gain can be calculated via:

$$\Phi_{i,\ month} \leq 5 \text{ x An (W)} \tag{8}$$

Here, A_n is the usage area of the building that can be obtained as follows:

$$\text{An} = 0{,}32 \text{ x Vgross} \tag{9}$$

V_{gross} is the heated gross volume of the building. On the other hand, the monthly solar gain ($\phi_{S,\ month}$) refers to the amount of energy gained by solar radiation from sunlight through the windows. The gains from passive solar energy systems are neglected in this work. The average solar gain is calculated using equation (10).

$$\Phi_{s,month} = \sum r_{i,month} \times g_{i,month} \times I_{i,month} \times A_i \qquad (10)$$

where, $r_{i,\ month}$ is the monthly average shading factor of transparent surfaces in “i” direction, $g_{i,\ month}$ denotes the solar energy transmission factor of transparent elements in “i” direction, $I_{,\ month}$ is the monthly average solar radiation intensity on vertical surfaces in the “i” direction, and A_i is the total window area in the "i" direction. While $r_{i,\ month}$ and $I_{,\ month}$ values are provided by the TS825, $g_{i,\ month}$ is calculated with the help of Eq. (11).

$$g_{i,month} = F_W g_{\perp} \qquad (11)$$

Here, F_w is the correction factor for glasses and $g_{\perp}$ denotes the solar energy transmission factor for the beam perpendicular to the surface measured under laboratory conditions. It is not always appropriate to consider the sum of the internal gains and solar energy gains as useful energy in terms of reducing the heating energy need. Because in times of high heat gains, the gains may be more than the instantaneous losses, or the gains may come when heating is not needed. The indoor temperature control system is not perfect, and some heat is stored in the building elements. Therefore, internal gains and solar gains are reduced by a utilization factor (η) that is the magnitude of this factor depends on the relative size of the gains and losses and the thermal mass of the building. The calculation of (η) is made using equations (9) and (10):

$$\eta_{month} = 1 - e^{(-1/KKO_{month})} \qquad (12)$$

where KKO_{month} is the gain/loss ratio, and it is calculated as follows:

$$KKO_{month} = (\Phi_{i,month} + \Phi_{s,month})/\mathrm{H}(\theta_{i,month} - \theta_{e,month}) \qquad (13)$$

Here, ϕ and θ are the abbreviation of heat gains and temperature levels. Note that, when the KKO_{month} value is 2.5 or above, it is considered that there is no heat loss for that month. The monthly average internal and external temperatures, $\theta_{i,ay}$ and $\theta_{e,ay}$ are provided by TS825 in Annex B, section 1 and 2 respectively.

2.1.2.3 Heating energy need value

With the help of the parameters calculated in the previous steps, we finally obtain the annual heating energy need for our building adding up the monthly heating energy need values for our building according to equations (14) and (15).

$$Q_{year} = \sum Q_{month} \tag{14}$$

$$Q_{month} = [\mathrm{H}(\theta_{i,month} - \theta_{e,month}) - \eta(\Phi_{i,month} + \Phi_{s,month})].\mathrm{t} \tag{15}$$

where, Q_{year} and Q_{month} are the annual and monthly heating energy need of the investigated building, t is the time in the unit of seconds.

2.1.3 Other energy needs of the building

The energy demand other than heating energy has been considered for the electrical devices used in the daycare. Main equipment list contain computer, washing Machine (A++), camera system, fridge (A++), deep-freeze (A+, 102L), microwave (A++), oven, fume hood and kettle. The annual energy requirement for these devices was calculated according to the number of devices, the power they consume and their respective daily working hours.

It is important to mention that the building investigated in our study lacks insulation in its components. Insulation represents a major parameter in the calculation method of TS825. The use of insulation material in the building components is recommended because it can bring potentially significantly high impact on the heat loss of the building by conduction, resulting in lower energy need [27]. Since the investigated daycare does not have any insulation material in its walls and other building components, we have conducted separate calculations for the heat loss through conduction and convection, assuming cases in which insulation materials are used for the walls and ceiling. The insulation material used for this purpose were selected according to the recommendations from TS825. This step is conducted for comparison purpose to analyze the impact of using insulation material as described in section2.3.

2.2 PV-panels selection and evaluation

The PV panel selection process is a crucial step in designing a solar energy system for energy buildings, especially zero-energy buildings. Once the energy demand of the selected building has been calculated for monthly and annual periods, PV panel type and required number of PV panels were investigated.

2.2.1 Parameters considered for the selection

The selection of the PV-panels was done according to the following criteria:

- requirements and objectives of the solar energy system
- amount of solar irradiation available at building location,
- power/efficiency of the panels,
- size of the panels and available area to be covered for installation of the system,
- PV panels availability of the Turkish market.

2.2.2 Building location and optimal tilt angle

The location of the building is another factor to consider as it defines the amount of solar irradiation that will be available to be converted to energy with our panels. The optimal orientation of the panels, or tilt angle, are then be calculated for each season.

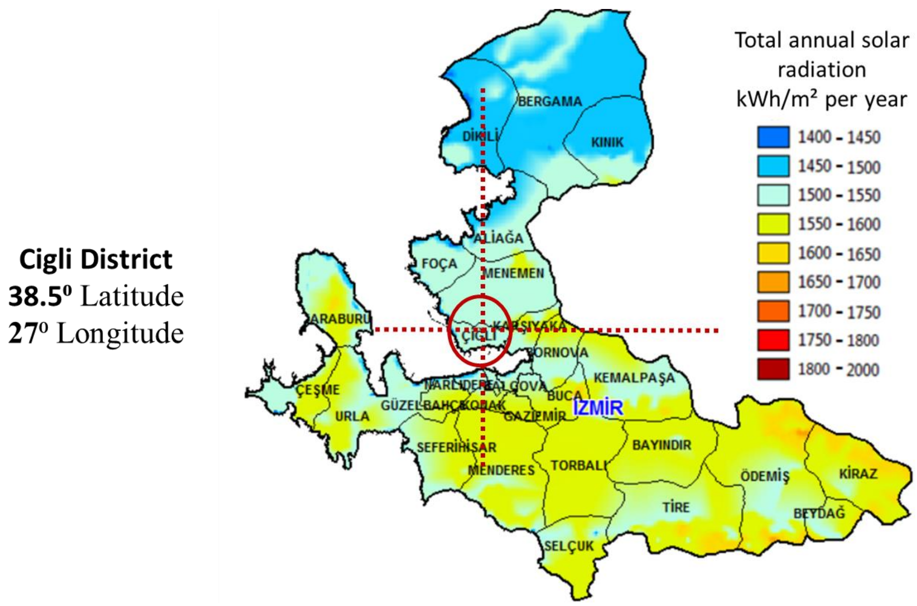

Figure 2.3 Solar irradiation map and latitude of Cigli district [28].

Figure 2.2 presents the solar irradiation map of Cigli district. Furthermore, latitude of the selected building is a crucial parameter for PV system design as tilt angle of the PV panels is directly depended on the latitude. We utilize from a simplified equation set to calculate the optimal tilt angle (β) of each season:

$$\begin{array}{rl} \text{During summer:} & \beta = (0.9 \times \text{Latitude}) - 23.5^{0} \\ \text{For spring and autumn months:} & \beta = \text{Latitude} \pm 2.5^{0} \\ \text{During winter:} & \beta = (0.9 \times \text{Latitude}) + 29^{0} \end{array} \qquad (16)$$

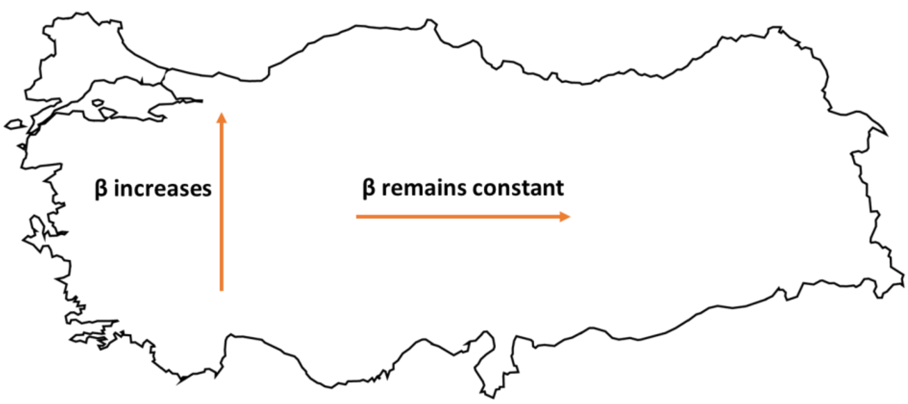

Figure 2.4. Effects of latitude and longitude on PV panel tilt angle.

PV panel orientation should be altered according to the PV panel tilt angle calculations. In most of the PV panel applications in our country, tilt angle is kept constant. In this case, an optimal angle value should be determined for annual radiant harvesting. Note that tilt angle only varies with latitude (Fig. 3). We may sum winter, summer, spring, autumn tilt angles and divide by four to find an approximate annual tilt angle. Another simplified equation can also be utilized for annually constant tilt angles:

$$\beta = (0.87 \times \text{Latitude}) + 3.1^{0} \tag{17}$$

2.3 Theoretical calculation of insulation impact

This section aims to assess the potential impact of insulation on the investigated building, considering that the building does not currently have any insulation in its components. The purpose of this step is to evaluate the significance of insulation and its effects on various parameters calculated previously.

- Insulation materials were selected based on the TS825 guidelines and relevant industry standards. (These materials are to be commonly used and readily available in the market or close enough to what is found in the market),
- three insulated cases were considered based on the different thermal conductivities of the insulation materials selected,
- heat loss, total energy requirement, and the corresponding PV panels requirement were calculated for each insulated case,
- the results obtained were compared to the real case study without insulation, to expose the differences in terms of heat loss reduction, energy savings, and the impact on the required capacity of PV panels.

2.4 Indoor air quality and personal comfort

The requirements for the wellbeing of the building's habitants were considered through the evaluation of the indoor air quality requirements and personal comfort of building habitants. This is an important factor to address for ensuring a healthy and comfortable living environment, as poor air quality can lead to various health issues and discomfort among occupants, particularly for children in the daycare facility. Furthermore, as the building in this case study is assumed to rely solely on natural ventilation without any mechanical ventilation system, it becomes even more critical to evaluate the effectiveness of the natural ventilation strategy in maintaining acceptable indoor air quality. By utilizing the ASHRAE standards 62.1 and 55, a comprehensive assessment of indoor air quality and personal comfort was conducted.

ASHRAE 62.1 was employed to determine the minimum ventilation rates necessary to achieve acceptable indoor air quality, even in the absence of mechanical ventilation systems. This standard provided guidelines on ventilation requirements for ensuring the maintenance of healthy indoor air. The method used takes into account various factors like building occupancy, floor area, and the activities performed within the space, the type of building, the number of occupants and the floor area.

Next, ASHRAE 55 was employed to evaluate thermal comfort parameters through The Predicted Mean Vote method. The Predicted Mean Vote (PMV) model is a key component of the ASHRAE 55 thermal comfort standard. It is a mathematical model used to predict the average thermal sensation of a group of people in a given indoor environment. The PMV model takes into account various environmental factors and personal parameters to assess thermal comfort. The PMV model is based on the concept of heat balance, where the heat produced by the human body is balanced with the heat exchanged with the surrounding environment. It considers six primary factors:

- Metabolic rate: the rate of heat production by the human body, expressed in units of metabolic equivalents, MET values (correspond to different levels of physical activity).
- Clothing insulation: thermal resistance provided by clothing worn by individuals. Measured in clo, where 1 clo is equivalent to the thermal insulation of typical indoor clothing.

- Air temperature: the common measure of indoor air temperature in degrees Celsius.
- Radiant temperature: the average temperature of all surrounding surfaces, including walls, floors, and ceilings, in degrees Celsius.
- Relative humidity: the average relative humidity in percentage of water vapor present in the air, at a given temperature.
- Air velocity: It denotes the average air speed at the occupant's level, in m/s.

By considering these parameters, the PMV model calculates a numerical index that represents the average thermal sensation of the occupants on a seven-point scale ranging from -3 (cold) to +3 (hot). The goal is to achieve a neutral thermal sensation (PMV close to 0) for the majority of occupants. In this view, The CBE Thermal Comfort Tool [29] came in handy for the computational work. This web-based tool for thermal comfort calculations according to ASHRAE Standard 55-2020 is developed at the University of California at Berkeley. It incorporates the major thermal comfort models and was used to calculate the PMV.

The integration of ASHRAE standards 62.1 and 55 allowed for a comprehensive evaluation and provided valuable guidance on strategies and measures to improve the indoor environment.

2.5 Cost analysis

The objective of the cost analysis is to evaluate the financial aspects of the project, specifically focusing on the cost associated with the PV panels, their installation, and the ongoing maintenance expenses. The aim is to provide a comprehensive understanding of the project's financial implications and evaluate the realistic implementation of the suggested PV-panel based energy system for each PV-panel selected. Information about panel prices, installation costs, and maintenance, were gathered online, directly from sellers' websites and experienced installers reviews. Furthermore, the period required for the return on investment (ROI) has been calculated via the annual electricity bill of the building when it uses energy from the local energy provider. Based on these data, a realistic estimation for the total cost of the project is provided.

Chapter 3

Results and Discussion

The results of our work using the methods described in section 2, are reported in this section. Parameters and properties used at each calculation step are described in tables and values found are reported.

3.1 Total energy requirement of the building

3.1.1 Heating energy need

3.1.1.1 Heat loss

As mentioned in the first section, the energy need for heating purpose in the building (H), is the dominant factor when determining the total energy need. It is defined in section 2 as the sum of heat loss through conduction and convection (H_T), and heat loss through ventilation. (H_v). Table 3.1 describes the calculation of (H_T).

Table 3.1. Building heat loss through conduction and convection: calculation steps

Surface type	Layer element	Element thickness d (m)	Thermal cond. λ (W/mK)	Conduction resistance R, (m^2K/W)	Overall coefficient U (W/m^2K)	Surface area A (m^2)	Heat loss A x U (W/K)
Wall surfaces	Ri			0,13			
	Plaster	0,02	1	0,02			
	lime sandstone	0,172	0,35	0,491			
	Plaster	0,008	0,35	0,023			
	Re			0,04			
Total				0,704	1,419	202,5	287,5
Wall surfaces (reinforced concrete)	Ri			0,13			
	Plaster	0,02	1	0,02			
	Reinforced Concrete	0,172	2,5	0,069			
	Plaster	0,008	0,35	0,023			
	Re			0,04			
Total				0,282	3,551	53,4	189,6
Ceiling	Ri			0,13			
	Plaster	0,02	1	0,02			
	Reinforced Concrete	0,18	2,5	0,072			
	Re			0,08			
Total				0,302	2,65	484,2	1478,3
Floor	Ri			0,17			
	PVC flooring	0,005	0,23	0,022			
	Screed	0,03	1,4	0,021			
	Leveling Screed	0,02	1,4	0,014			
	lightweight concrete	0,1	1,1	0,091			
	Re			0			
Total				0,317	1,573	484,2	761,9
External Door					4	7,92	31,68
Window					2,4	65,48	157,15
Sum of the heat loss from the building elements by conduction and convection HT,							2710,428

The value for the total heat loss through conduction and convection of the daycare was found as H_T = 2710,428 W/K. Next, the heat loss through ventilation, (only natural ventilation in our building) was calculated using Eq. (7) and the following value was found as H_V = 378.3 W/K. Finally, the total heat loss of the building was obtained by summing up H_T and H_V according to equation (1). The total heat loss coefficient of the building is **H = 3088.78 W/K.**

3.1.1.2 Heat gains

Once the heat losses due to the building structure and ventilation system were determined, we calculated the heat gains (ϕ) of the building as the sum of internal gains (ϕ_i) and solar gains (ϕ_s). The internal heat gain was calculated as an average value using Eq. (9), which is about $\phi_i = 2866.3$ W. On the other hand, the average solar gain was calculated monthly, in each cardinal direction, as described in Eq. (10). The calculation steps and results are reported in Table 3.2. Note that $r_{i,month}$ and $g_{i,month}$ values are taken from the TS 825 standard as 0,8 and 0,68, respectively.

Table 3.2 Average monthly solar gains: calculation steps

	$I_{i,ay}$			**A_i (m^2)**				**ϕ_s**
	I_{South}	I_{North}	$I_{East/West}$	A_{South}	A_{North}	A_{East}	A_{West}	(W)
Jan.	72	26	43	15,6	20,58	16,3	13	1587,5
Feb.	84	37	57					2035,6
Mar.	87	52	77					2547,8
Apr.	90	66	90					2937,2
May	92	79	114					3482,3
Jun.	95	83	122					3680
Jul.	93	81	118					3576,9
Aug.	93	73	106					3296,1
Sept.	89	57	81					2684,5
Oct.	82	40	59					2084,1
Nov.	67	27	41					1524,4
Dec.	64	22	37					1379,2

Gain utilization factor was calculated for each month via Eq. 12, and the values are reported in Table 3.3.

3.1.1.3 Heating energy need value

At last, the annual heating energy requirement of the building (Q_{year}), was determined as the sum of the monthly heating energy requirement values (Q_{month}) by using Eqs. (14) and (15), respectively. The calculation steps and results are presented in Table 3.3

Table 3.3. Main calculation steps and results on the annual heating energy requirement of the building.

	Heat losses			Heat gains				
	Specific Heat loss	Temp. diff.	Heat loss	Internal heat gain	Solar energy gain	KKO	Gain util. factor	Heating energy requirement
Months	$H=H_T+H_V$ (W/K)	θ_i-θ_e (K,°C)	$H(\theta_i$-$\theta_e)$ (W)	ϕ_i (W)	ϕ_s (W)	γ (-)	η_{month} (-)	Q_{month} (kJ)
Jan.	3088.78	11,6	35829,86	2866,3	1587,5	0,12	0,99	$8,13\times10^7$
Feb.		11	33976,6		2035,6	0,14	0,99	$7,53\times10^7$
Mar.		8,4	25945,76		2547,8	0,20	0,99	$5,33\times10^7$
Apr.		4,2	12972,88		2937,2	0,42	0,90	$2,02\times10^7$
May		θ_e high	0		3482,3	0	0	0
Jun.		θ_e high	0		3680	0	0	0
Jul.		θ_e high	0		3576,9	0	0	0
Aug.		θ_e high	0		3296,1	0	0	0
Sept.		θ_e high	0		2684,5	0	0	0
Oct.		1,5	4633,18		2084,1	1,004	0,63	$4,21\times10^6$
Nov.		7	21621,47		1524,4	0,190	0,99	$4,47\times10^7$
Dec.		10,7	33049,94		1379,2	0,12	0,99	$7,47\times10^7$

The total heating energy requirement of the building was calculated as the sum of the monthly heating energy needs, and found as: $\mathbf{Q_{year} = 3,54 \times10^8}$ **kJ**. This value corresponds to $9,83 \times10^4$ kWh. This theoretical value obtained using the TS 825 standard assumes a permanent daily and monthly use of electricity in the building. In reality, the building is functional 12 hours a day, 23 days a month, or 276 hours monthly. It represents only 38% of 720 hours calculated. This means that in reality, only 38% of the energy calculated is needed. The real heating energy requirement becomes **3,74×10^4 kWh**.

3.1.2 Other energy needs and Total energy requirement

The remaining energy requirement for the daycare was assessed by identifying all devices consuming electricity in the building and calculating their monthly and annual consumption, reported in Table 3.4.

Table 3.4. Annual energy consumption of devices in the daycare

Device	Pcs.	Power (W)	Daily working hour (h)	Daily Energy consumption (KWh)	Monthly energy consumption (KWh)	Annual energy Consumption (KWh)
Computer	1	15,2	8	0,12	3,6	108
Washing Machine (A++)	1	800	1	0,8	24	720
Camera System	1	10	24	0,24	7,2	216
Fridge (a++)	1	60	24	1,44	43,2	1296
Deep Freeze (A+, 102 liters)	1	50	24	1,2	36	1080
Microwave (A++)	1	300	1	0,3	9	270
Oven	1	2500	1	2,5	75	2250
Fume Hood	1	12	1	0,012	0,36	10,8
Kettle	1	1200	0,5	0,6	18	540
	1	28	8	0,224	6,72	201,6
Total				7,436	223,1	6692,4

We have calculated that the annual energy consumption of electrical devices used in the daycare is about 6692,4 kWh; therefore, the total energy requirement of the building per year rises to **4,40×10^4 kWh**. Parameters and properties used at each calculation step are described in tables and values found are reported.

3.2 PV-panel selection and investigation

Five different types of PV-panels were investigated to provide the amount of energy needed for the investigated daycare. The criteria considered for this selection are the amount of solar irradiation at the building location, the total area to be covered with PV-panels considering individual panel size, and the calculated energy requirement of the building.

3.2.1 Solar irradiation at the building location

The average daily irradiation time for each month at the building location are presented in Table 3.5.

Table 3.5. Cigli district annual sunbathing time [28].

Month	**Duration (h)**
January	4,98
February	5,99
March	7,17
April	8,19
May	9,88
June	12,07
July	12,38
August	11,6
September	9,8
October	7,78
November	5,69
December	4,39

3.2.2 Required number of PV-panels and area

The types of PV-panels investigated in our work and their properties are reported in Table 3.6.

Table 3.6. Monocrystalline PV-panels and main properties [30].

Panel	Power (W)	Dimensions (mm)	Weigh (kg)	Efficiency (%)	Price (TRY)
Jinko Solar JKM370M-72-J	370	1956×992×50	27	19.1	3689
Jinko Solar JKM535M-72H	535	2278×1134×35	28	20.8	5632
Lexron LXR-410M	410	1987×1001×35	22	19.1	5044
AlfaSolar 3S72M400	400	1994×1008×42	24	20.0	4016
ELINPlus ELNSM6612M	395	1979×1002×40	22.5	19.9	3965

For each PV-panel type investigated, the corresponding number of panels and the total area needed to provide the amount of energy requirement of the daycare, were calculated according to the amount of solar irradiation. The calculation was made for the month of January as it is the month during which the energy need reaches its peak value: 9142,58 kWh. Table 3.7 presents the values obtained.

Table 3.7. Number of PV-Panels required and area to be covered

PV-Panel	Solar Irradiation time (Jan.) (h)	Panel Power (kW)	Energy generation (Jan) (kWh)	Energy requirement (Jan.) (kWh)	Number of PV	Single panel area (m^2)	Total surface needed (m^2)
Jinko Solar JKM370M-72-J	149,4	0,37	55,28	9142,58	166	1,95	320,93
Jinko Solar JKM535M-72H		0,535	79,93		115	2,59	295,5
Lexron LXR-410M		0,41	61,26		150	1,99	296,87
AlfaSolar 3S72M400		0,4	59,78		153	2,01	307,5
ELINPlus ELNSM6612M		0,395	59,1		155	1,99	307,21

We observed that with the PV-panels investigated, the number of panels needed to cover the daycare energy needs, is in the range of 115 to 166, meaning an average of 140 panels depending on the panel power. It corresponds to an area between 307 and 321 m^2, or an average of 315 m^2 while the roof area of our building is 485m^2, the required area values found are just in the range, assuming the whole roof area will be used. Among our PV-panels, the best performer is the Jinko Solar JKM535M-72H: with its efficiency of 20.8% it can generate enough energy for the daycare with 115 panels, which represents a surface of just 296 m^2.

As mentioned in the previous sections, the calculations for determining the required number of PV panels required were based on the month of January, as it experiences the highest heating energy demand while the total sunbathing time is limited. By focusing on that period, we aimed to ensure that the energy supply through PV-panels would be sufficient to meet the peak energy requirements. However, in this work, the amount of energy generated and provided to the building via the PV-panels, is the same energy that is directly used, without modification, to meet the energy demand. This assumes the use of a heat pump with a fixed Coefficient of Performance (COP) equal to 1. This assumption allows for a simplified analysis and provides a starting point to evaluate the feasibility of utilizing PV solar cells to meet the energy needs of the daycare building. However, it is important to note that a COP of 1 represents the least efficient mode of operation for a heat pump system.

In non-zero energy buildings (NZEBs), where commercial heat pump systems are commonly used, the COP values typically exceed 1. Nowadays, the COP of a decent heat pump can range from 2 to 4, indicating that for every unit of electrical energy input, the heat pump can provide 2 to 4 units of heat energy output [31]. Higher COP implies greater energy efficiency and lower energy consumption.

By including this parameter in the analysis, it becomes evident that a better-performing heat pump would significantly affect the total number of PV panels needed for the project. With a higher COP, the heat pump would provide more heating energy output for the same amount of electrical energy input, reducing the overall number of PV panels required to meet the energy demand. It offers valuable optimization opportunity for the system.

3.2.3 Optimal tilt angle

The optimal tilt angle (β) for the panels was calculated for the investigated building located in the Cilgi district in Izmir, at a latitude of 38,5º. The results are reported in Table 3.8.

Table 3.8. Optimal tilt angle for Cilgi district

Season	β
Summer	11,15
Spring	41
Autumn	36
Winter	63,65

Alternatively, a constant value for (β) can also be calculated using eq. (17) in case the solar panel will stay in the same direction all through the year.

3.3 Impact of insulation

As mentioned in the previous sections, our building does not have insulation although it is recommended in the TS825 standard. In this view, we have conducted theoretical calculations assuming cases in which a layer of insulation material is applied to the walls and the ceiling components of the daycare. Three cases have been considered. For each case, a different insulation material was selected for the walls, while one single material was maintained for the ceiling in all three cases. The materials used for the wall insulation are Extruded Polystyrene (XPS) Styrofoam, Glass foam, and Wood fiber, while the ceiling insulation was evaluated using Expanded Polystyrene (EPS) Styrofoam. These materials were selected based on their thermal conductivity values in accordance with the suggestions from TS828, and their availability on the market. The thickness of the materials is an important factor when considering insulation. Thicker layers allow better insulation, but they should remain in compliance with local building codes and regulations. In our work, we have calculated the thickness of the investigated materials in order to obtain a reduction of 50% in heat loss through conduction and convection (H_T) value, for each case considered. The insulation materials investigated with their properties and the calculated thickness values required for the desired insulation performance are shown in Table 3.9.

Table 3.9. Properties of insulation materials used in experimental cases

	Wall insulation			Ceiling insulation
Material	Case 1	Case 2	Case 3	EPS Styrofoam
	XPS Styrofoam	Glass foam	Wood fibered	
Thermal conductivity (W/mK)	0,035	0,055	0,065	0,04
Thickness required (m)	0,01536	0,0158	0,016	0,02

The impact of these insulation materials on the heat loss and the total energy demand of the building were calculated and compared with the real case where there is no insulation. The results are presented in table 3.10.

Table 3.10. Impact of insulation on heat loss and total energy demand

	Insulation Material	Thermal conductivity (W/mK)	Thickness required (m)	Heat loss (W/K)	Energy need (kWh)
Case 1	XPS Styrofoam	0,035	0,01536	2180	63730,39
Case 2	Glass foam	0,055	0,0158	2206	64748,32
Case 3	Wood fibered	0,065	0,016	2215	65087,57
Real Case	No insulation			3088,79	98292,18

As we can see from these results, the use of insulation material to reduce (H_T) value by 50%, results in 29.4%, 28.5% and 28.2% drops in heat loss for insulation cases 1, 2 and 3 respectively.

Consequently, the annual total energy need of the building in each of the three insulation cases drops by 35.2%, 34.1%, and 33.8% respectively. With these new values, the corresponding number of PV panels required was determined for the three insulated cases, with each of the five PV-panels selected previously, and comparison was made with the real situation where there is no insulation. These results are detailed in Table 3.11.

Table 3.11. Number of PV-panels needed for insulation cases

	Case 1	Case 2	Case 3	Real Case
Jinko Solar JKM370M-72-J	113	115	115	165
Jinko Solar JKM535M-72H	78	79	80	114
Lexron LXR-410M	102	104	104	149
AlfaSolar 3S72M400	105	106	107	153
ELINPlus ELNSM6612M	106	108	108	155

As shown from these results, when insulation is applied, the number of PV-panels needed to cover the entire energy need of the daycare decreases by approximately 30% depending on the PV-panel used. From these panels, the Jinko Solar JKM535M-72H has the best performance and would allow to cover the energy demand with just 78, 79, or 80 panels in each of the three insulated cases respectively, while the initial case without insulation requires 114 panels. We observe here the use of insulation plays a very important role in limiting the heat loss of the building, allowing the energy need to decrease significantly. While our theoretical study assumed insulation layers only on the wall surface and ceiling components of the building, it is important to remember that insulation layers can also be applied to other components like the reinforced concrete part of the walls or the floor. Furthermore, the thickness of the insulation layers used in our study was minimized in order to provide the most realistic case possible, but the average thickness of insulation layers is well above our values, as it can be seen in the examples from the TS825 standard, where the thickness of the layers is about 3 times our value. All these remarks imply that the use of insulation have potential to reduce the energy need value by tremendous amount.

3.4 Requirements for indoor air quality and personal comfort

In the context of implementing a net-zero energy building, we have previously highlighted the importance of taking into consideration the quality of the inside environment from an individual perspective, aiming to provide guidance and directives to follow for the wellbeing of kids. The following aspects were considered and evaluated.

The calculation of the minimum ventilation rates necessary to achieve acceptable indoor air quality in the building was based on the ASHRAE standards 62.1 method with the following parameters:

- Type of building: daycare (educational facility)
- Number of occupants: 50 kids (max building's capacity) + 5 teachers = 55
- Floor area: 485 m^2

For an educational facility, the recommended ventilation rate is 5 l/s/person. The ventilation rate required in this case, with 55 occupants, is 50 × 5 l/s/person = 275 l/s. ASHRAE 62.1 provides adjustment factors to account for the floor area of the building. For educational facilities, the adjustment factor is 0.9 $m^3/s/m^2$. We multiply this adjustment factor by the floor area of the daycare building to determine the adjustment ventilation rate. Our adjustment ventilation rate is then found as 485 $m^2 \times 0.9\ m^3/s/m^2 = 436.5\ m^3/s$.

To determine the total ventilation rate, we add the ventilation rate previously calculated and the adjustment ventilation rate. The total ventilation rate requirement for the daycare is found as 275 l/s + 436.5 m^3/s = **711.5 l/s**.

Next, the thermal comfort standard is evaluated based on the ASHRAE 55 method, by The Predicted Mean Vote (PMV) which is computed with the help of the CBE Thermal Comfort Tool. Figure 3.1 shows the input data used with the tool.

Note that the air speed was deducted from the ventilation rate value for natural ventilation through the windows area. Likewise, the relative humidity was assumed as 40%, based on the recommended range for personal comfort in buildings [32]. The metabolic rate was selected slightly above steady state, the other data are kept as shown in the Figure3.1.

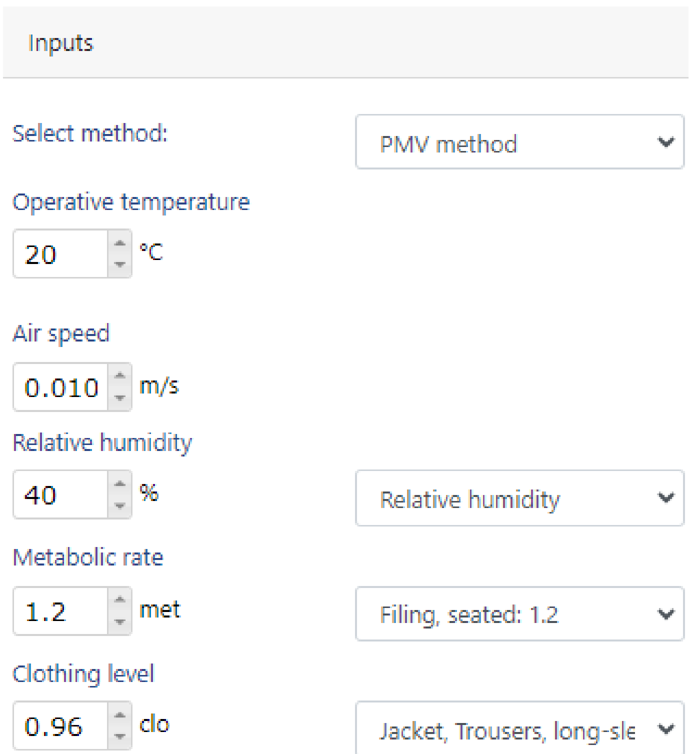

Figure 3.1: Input data for CBE Thermal Comfort Tool

The results of the tool computations are presented in Figure 3.2.

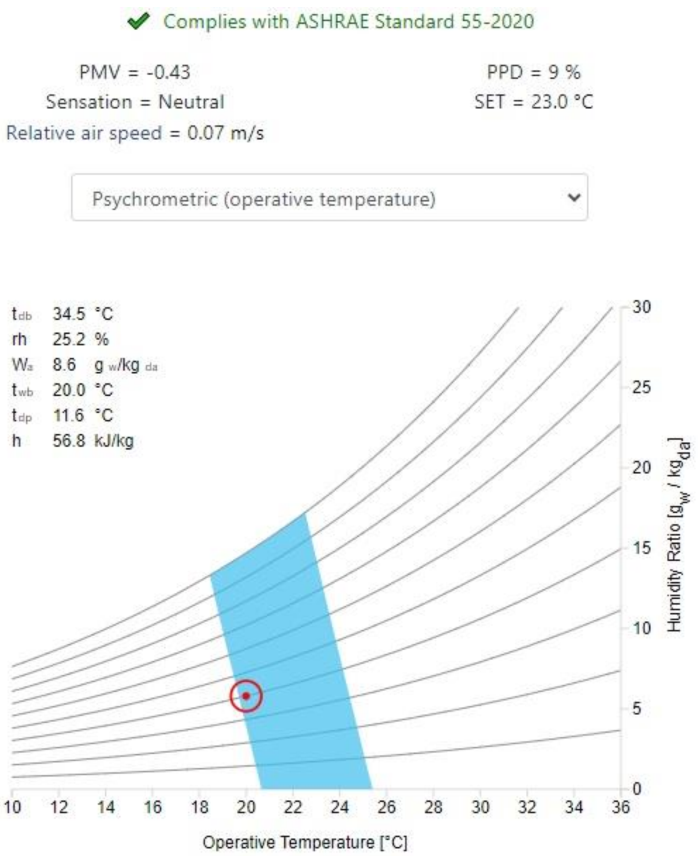

Figure 3.2: CBE Thermal Comfort Tool computation results

As we can see from the computation results, the CBE Thermal Comfort Tool plots a graph of operative temperature versus humidity ratio and thus provides an accurate estimation of the PMV value, -0.43 in our case, confirming no discomfort, or say neutral sensation for the occupants with the given values.

These calculations provide an estimate of the minimum ventilation rate required for the daycare building and a guideline for the evaluation of the wellbeing of its habitants based on ASHRAE 62.1 and 55 methods. Note that the calculations are theoretical and certain values are estimated and can slightly differ from reality.

Additionally, the incorporation of a Heat recovery ventilation (HRV) system is an important parameter to be explored as it aligns with the goal of creating a sustainable and energy-efficient building [33]. HRV systems capture and transfer heat energy from the exhaust air stream to the incoming fresh air stream in a building, or vice versa. This involves the use of a heat exchanger or heat recovery unit to extract heat from the stale air being expelled from the building and transfer it to the fresh air entering the building. This process helps to reduce energy consumption for heating and cooling, improves indoor air quality, and enhances overall building efficiency. Furthermore, HRV can significantly enhance indoor air quality by providing a constant supply of fresh, filtered air while efficiently removing pollutants, allergens, and excess humidity from the building. This is particularly important for daycare facilities, where maintaining a healthy and comfortable indoor environment is crucial for the well-being and health of the children. The necessary capacity of the HRV system can be calculated based on the airflow requirements and ventilation rates of the building using established guidelines and standards such as ASHRAE 62.1 or local building codes. An optimal HRV system can then be integrated to the existing HVAC system of the building. The implementation of HRV can offer significant optimization options to the project and deserves further evaluation.

3.5 Cost analysis

In order to evaluate the real cost of utilizing the investigated PV-panels to meet the total energy demand of the daycare building, a cost analysis was conducted. This analysis takes into account the price of the PV-panels, estimation of Turkish market prices for installation and maintenance costs, as well as a calculation of the return-on-investment. The prices of the investigated PV-panels are provided in Table 3.12.

Table 3.12. Total price of the PV-Panels

Panel	Price for single panel (TRY)	Number of panels	Total Price (TRY)
Jinko Solar JKM370M-72-J	3689	166	612374
Jinko Solar JKM535M-72H	5632	115	647680
Lexron LXR-410M	5044	150	756600
AlfaSolar 3S72M400	4016	153	614448
ELINPlus ELNSM6612M	3965	155	614575

The price varies from approximately 613000TRY to 757000TRY, depending on the type of PV-panel used, with an average of 700000TRY.

The overall installation cost can include additional expenses (like the cost of inverters, mounting hardware, wiring and so on). These additional costs can vary widely depending on the specifics of the installation site and local labor rates. The most recent information we have gathered concerning the installation price for PV-panels from suppliers and reviewers indicates that the overall installation of solar panels costs between 21TRY and 25TRY per Watt installed [34], [35]. This value is fairly in the range of prices given by Forbes [36] for PV-panels installation in the US. This represents on average of 1.4 million TRY to be paid for labor. The total cost of the project is found to be in the range of **2.023 to 2.18 million TRY**. The maintenance of PV-panels is estimated to be between 1% and 2% of the installation cost. In our case, this represents approximately 21000TRY per year.

On the other hand, when we consider the insulated cases, the cost of PV-panels changes according to the new number of PV-panels needed to cover the energy demand. For each case, the total prices of the PV-panels, are detailed in Table 3.13.

Table 3.13. Total price of the PV-Panels for insulated cases

Panel	Price for single panel (TRY)	Number of panels			Total Price		
		Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Jinko Solar JKM370M-72-J	3689	113	115	115	417672	423399	425307
Jinko Solar JKM535M-72H	5632	78	79	80	440998	447046	449060
Lexron LXR-410M	5044	102	104	104	515370	522437	524791
AlfaSolar 3S72M400	4016	105	106	107	420593	426360	428281
ELINPlus ELNSM6612M	3965	106	108	108	420508	426274	428195

The results show that the total prices of the PV panels decrease by around 30% for the insulation cases.

The price of the insulation materials was calculated according to their unit price and the surface to be covered: 202.5m of wall surface, and 484.1m for the ceiling. Table 3.14 shows an estimation of these prices for each case.

Table 3.14. Price of insulation materials

	Material	Price (TRY)
Case 1	XPS Styrofoam	21796,93
Case 2	Glass foam	65390,78
Case 3	Wood fibered	54492,32
Ceiling	EPS Styrofoam	3647,57

In order to get the total cost of the project, the labor cost was also calculated with the same method used previously for the real case, and found to be in the range of 966000TRY and 985000TRY. According to these data, the total cost of the project for insulation cases ranges between **1.38 and 1.56 million TRY**.

To calculate the Return on Investment we divide the total investment cost (including PV panels, installation, and labor) by the annual energy bill savings:

Annual Electricity Consumption: 4.40×10^4 kWh

Cost per kWh from the grid with current provider: 3.7839 TRY [37]

Annual Energy Bill without PV-Panels: $4.40x10^4$ kWh × 3.7839 TRY = 166,527.6 TRY

Annual Energy Bill Savings: 166,527.6 TRY (full coverage with PV-panels)

Total Investment Cost: 2.1 million TRY

ROI Period: 2.1 million TRY / 166,527.6 TRY = 12.60 years

Therefore, ROI period for the project is approximately **12.60 years**.

Likewise, the ROI calculation when insulation is used, gives the following result:

Total Investment Cost for insulated cases: 1.56 million TRY

ROI Period: 1.56 million TRY / 166,527.6 TRY = 9.36 years

The use of insulation allows for the ROI period to drop to approximately **9.36 years**.

Note that in these calculations, the COP value of the heat pump to be used is assumed to have the lowest possible efficiency, while in practice the heat pumps available on the market have COP values above 2 [38]. When integrating this parameter in the calculation, for a heat pump with a COP of 2, the energy generation doubles for the same energy input, theoretically reducing by 50% the heating energy needs. From $3,74\times10^4$ kWh, the value would drop to 1.87×10^4 kWh, hence, the total annual energy need of the building in this case, would drop to 2.54×10^4 kWh. This represents a drop of 42.27% in the total energy need. As the number of PV-panels is directly proportional to the energy need, it would also be reduced by 42%, causing the initial cost of the project to drop by the same percentage and become 1.21 million TRY. Accordingly, the ROI period in this case would drop to 1.21 million TRY/ 166,527.6 TRY ≈ **7.27 years**. For the same scenario, when insulation is used, we obtain a ROI period ≈ **5.40 years**.

This period is a more realistic estimation of what we can expect in practice when implementing the project. This ROI value is expected to drop even deeper over the coming years due to the growing inflation rate that will result in higher electricity bills.

Chapter 4

Conclusion and Recommendations

Zero-energy buildings are important because residential and commercial buildings consume a significant amount of primary energy and electricity, leading to environmental and economic challenges. The global increase in energy demand and the need for sustainable and environmentally friendly solutions, has led to a growing interest in renewable energy sources such as solar power and emphasized the importance of solutions like PV-aided net zero-energy buildings.

In this thesis, we have explored the feasibility of meeting the energy needs of the daycare building at IKCU through the use of photovoltaic (PV) solar cells. Our study focused on the heating, ventilation, and air conditioning (HVAC) energy requirements, as they represent the biggest share in both residential and commercial buildings.

By utilizing the TS825 standard, which provides guidelines for calculating the energy performance of buildings, the heating energy requirement of the daycare building was determined. The analysis took into account factors such as building dimensions, thermal insulation properties, heat losses, and heat gains. The monthly and annual energy demand of the building was accurately estimated based on these calculations. We then considered other energy needs, including lighting and electrical devices, to determine the overall energy requirement of the building.

Based on our analysis, we proposed the use of monocrystalline PV panels to meet the energy demand of the daycare building. After scaling the selected PV-panels to our project, the orientation and power potential of the PV panels were determined based on the maximum energy requirement experienced in January.

The required number of PV-panels needed to cover the energy demand of the building was found to be in the range of 115 to 166 panels.

Since our building lacks insulation which is an important parameter when dealing with heat loss and energy demand in buildings, as shown in the TS825 standard, theoretical calculations were conducted, assuming the presence of insulation layers in the walls and the ceiling components of our building. Three cases have been considered. For each case, a different material with different thermal conductivity was selected for the wall insulation, while one standard material was kept constant for the ceiling insulation. Comparison between the results of real case without insulation and theoretical cases with insulation, showed that the total energy demand of the building can be reduced by 33.8%, 34.1%, and 35.2%, which are very significant values. Likewise, the number of PV-panels required to cover the energy demand of the daycare dropped by approximately 30%, with an optimal value of just 78 PV-panels, using the Jinko Solar JKM535M-72H under the insulation conditions described in case 1.

The wellbeing of the children in the building was theoretically evaluated based on ASHRAE 62.1 and 55 standards and gives an insight on possible pathways and methods to follow in assessing the ventilation rate requirement and the conditions for individual comfort.

Lastly, we conducted a cost analysis to evaluate the economic aspects of implementing the solutions suggested. The total cost of the project includes the price of the panels and the labor for installation and was found in the range of 2.023 to 2.18 million TRY depending on the PV -panel selected. The initial investment associated with implementing a PV panel system capable of meeting the entire energy demand of the building may represent a challenge, especially for buildings with limited budgets. The ROI period was evaluated at 12.60 years in the real case and at 9.36 years when insulation is used. Throughout our work, the heat pump to be used is assumed to have the lowest efficiency, with a COP of 1. In practice, heat pumps used today have COP values ranging from 2 to 4. The use of a standard heat pump with a COP as low as 2, suggested that the requirements on the heating energy needs would drop by 2, causing total energy need to drop by 42.27%. The initial investment, in this case, would also drop by the same percentage, resulting in a ROI period of **7.27** years in the real case, and 5.40 years for the insulated case. These results offering very optimistic perspective for the implementation of the project.

The use of insulation is a main recommendation in view of the implementation of the project. Research has shown that insulation allows this initial investment to be reduced by a very significant amount, confirmed by our result, as the total cost of the project dropped to values between 1.38 and 1.56 million TRY. Furthermore, insulation has potential to reduce the initial cost even more, as layers could be applied to other components of the building. A vast selection of insulation materials can be chosen from, according to the cost and the thermal conductivity. The optimal thickness of insulation materials can be determined according to the building regulation and the desired insulation performance [39].

The thermal comfort of the habitants was estimated using simplified assessment methods as it is not the main objective of this research. Integrating an HRV system to the analysis showed potential in reducing energy consumption and improvement of indoor air quality, resulting in better overall building efficiency. Additional guidelines provided by ASHRAE standards 62.1 and 55 should also be considered for the implementation of a more effective natural ventilation system and could also be considered to ensure optimal indoor air quality.

Our next recommendations towards better effectiveness of the project, is the use of energy storage technologies. Considering the fact that solar energy is intermittent, using storage technologies to get a good balance between days of peak irradiation and days with lesser sunbathing time, can certainly have a great positive impact. In a publication from Vieira, F. M. et al [40], this point is deeply investigated. The objective of their research on the use of the energy storage system is to increase the matching between local generation and consumption and reduce the energy bill. The system uses lithium-ion batteries for energy storage and was modeled and simulated using real data from a residential household in Coimbra, Portugal. The results of the simulation show that the designed energy storage system was able to significantly reduce the energy consumed from the grid as it was reduced by 78.3% and the system was able to reduce the energy bill by 87.2%.

Some other options remain available to make the project more realistic and deserve further evaluations. The ideal case for ZEBs would be that the initial construction of the building is made by implementing directly energy-efficiency principles and careful planning. For buildings that didn't integrate a designed structure for ZEB energy system structure, retrofitting is the best alternative. Indeed, even though sometimes older buildings may not result in ZEBs, the energy consumption and costs can still be significantly reduced. Besides that, a more specific PV-panel system could be considered, with usage exclusively limited to the ideal irradiation conditions, allowing a reduced dependance on energy from the grid. These recommendations for ZEBs improvement are supported by Torcellini, P. A., & Crawley, D. B in their publication on understanding ZEBs [41]. The authors explain how design teams play a crucial role in influencing the energy future by creating low-energy buildings and encouraging owners to follow energy-efficient paths. Thermal envelope design, daylighting with automated controls, natural ventilation, and right-sizing HVAC systems are important considerations.

Overall, our findings suggest that it is indeed possible to cover the entire energy needs of the daycare building through PV-panels, making it a net zero-energy building. The use of renewable energy sources like solar power not only reduces greenhouse gas emissions but also contributes to a sustainable and environmentally friendly future. The results of this study provide valuable insights and recommendations for improving energy efficiency in commercial and residential buildings.

References

[1] International Energy Agency (IEA). (2020). World Energy Outlook 2020.

[2] International Renewable Energy Agency. Renewable power generation costs in 2020. IRENA; 2020.

[3] Pandey AK, Tyagi V, Selvaraj L, Rahim NA, Tyagi SK. Recent advances in solar photovoltaic systems for emerging trends and advanced applications. Renewable and Sustainable Energy Reviews. 2016.

[4] Jäger-Waldau A. PV status report 2014. Eur Union 2014; 5:5–6.

[5] Rogers J, Wisland L. Solar Power on the Rise: The Technologies and Policies behind a Booming Energy Sector. Union of Concerned Scientists; 2014 Jul 1.

[6] Jaysawal RK, Chakraborty S, Elangovan D, Padmanaban S. Concept of net zero energy buildings (NZEB) - A literature review. Cleaner Eng Technol. 2022

[7] Iqbal, M., 2004. A feasibility study of a zero-energy home in Newfoundland, 2004 Renew. Energy 29 (2), 277–289. ISSN 0960-1481.

[8] Kilkis, S., 2007. A new metric for net- zero carbon buildings. Proceedings of ES2007. In: Energy Sustainability 2007, Long Beach, California, pp. 219–224.

[9] Laustsen, J., 2008. Energy Efficiency Requirements in Building Codes. Energy Efficiency. Lund, H., Marszal, A., Heiselberg, P., 2011. Zero energy buildings and mismatch compensation factors. Energy Build. 43 (7), 1646–1654.

[10] Noguchi, M., Athienitis, A., Delisle, V., Ayoubm, J., Berneche, B., 2008. Net Zero Energy Homes of the Future: A Case Study of the Eco Terra House in Canada.

[11] Pless, S., & Torcellini, P. (2007). Net Zero Energy Buildings: A Classification System Based on Renewable Energy Supply Options. National Renewable Energy Laboratory. (Report No. NREL/CP-550-39833)

[12] Charron R. A review of low and net-zero energy solar home initiatives. Article. January 2005; Volume (Issue): Page range. New York Institute of Technology, Vancouver, Canada.

[13] González-Torres, M., Pérez-Lombard, L., Coronel, J. F., Maestre, I. R., & Yan, D. (2022). A review on buildings energy information: Trends, end-uses, fuels and drivers. Energy Reports, 8, 626-637.

[14] National Academies of Sciences, Engineering, and Medicine. 2010. Real Prospects for Energy Efficiency in the United States. Washington, DC: The National Academies Press. https://doi.org/10.17226/12621.

[15] Fajardy M, Reiner DM. An overview of the electrification of residential and commercial heating and cooling and prospects for decarbonisation. Energy Policy Research Group, University of Cambridge; 2020 Dec 1.

[16] Duffie JA, Beckman WA. Solar engineering of thermal processes. 4th ed. Hoboken, NJ: John Wiley & Sons, Inc; 2013.

[17] Clarke JA. Energy simulation in building design. 2nd ed. Oxford, UK: Butterworth-Heinemann; 2001.

[18] Kalogirou SA. Artificial intelligence for the modeling and control of combustion processes: a review. Progress in Energy and Combustion Science. 2003;29(6):515-566.

[19] Turkish Standards Institution (TSE). Energy Performance of Buildings - Calculation of Energy Use for Heating and Cooling, TS 825. Ankara: TSE; 2018.

[20] Zhao, Kang, et al. "The method of reducing heat loss from thermal bridges in residential buildings with internal insulation in the hot summer and cold winter zone of China." Journal of Building Engineering 62 (2022): 105421

[21] Aditya, Lisa, et al. "A review on insulation materials for energy conservation in buildings." Renewable and sustainable energy reviews 73 (2017): 1352-1365.

[22] International Energy Agency. "Net Zero by 2050: a Roadmap for the Global Energy Sector." 2021, May 18.

[23] MARADIN, Dario. Advantages and disadvantages of renewable energy sources utilization. International Journal of Energy Economics and Policy, 2021.Standard

[24] Zeiler W. Net-Zero Energy Building: the two major drawbacks. In Proceedings Sustainable Building Euregional Conference 2010 'Towards 0-impact buildings and environments', Maastricht, Heusden-Zolder, Aachen, Liege, 11-13 Oktober 2010. 2010. p. 1-8

[25] 62.1-2022 -- Ventilation and Acceptable Indoor Air Quality (ANSI Approved) STANDARD by ASHRAE, 2022

[26] Standard 55-2017 -- Thermal Environmental Conditions for Human Occupancy (ANSI/ASHRAE Approved) STANDARD by ASHRAE, 2017

[27] Mishra, Subhash, J. A. Usmani, and Sanjeev Varshney. "Energy saving analysis in building walls through thermal insulation system." International Journal of Engineering Research and Applications 2.5 (2012): 128-135.

[28] Güneş Enerji Potansiyel Atlası (GEPA), https://gepa.enerji.gov.tr/MyCalculator/pages/35.aspx.

[29] Tartarini, F., Schiavon, S., Cheung, T., Hoyt, T., 2020. CBE Thermal Comfort Tool: online tool for thermal comfort calculations and visualizations. SoftwareX 12, 100563. https://doi.org/10.1016/j.softx.2020.100563

[30] Website for PV panel properties, https://solaravm.com/solar-gunes-paneli, Last accessed: May 5th,2023.

[31] IEA (2022), The Future of Heat Pumps, IEA, Paris https://www.iea.org/reports/the-future-of-heat-pumps, License: CC BY 4.0

[32] GHIDA, D. Ben. Heat recovery ventilation for energy-efficient buildings: design, operation and maintenance. International Journal of Innovative Technology and Exploring Engineering, 2019, vol. 9, no 1, p. 3713-3715.r

[33] Olesen, Bjarne W. "Guidelines for comfort." Ashrae Journal 42.8 (2000): 41-47.

[34] https://www.globalenerjimarketim.com/

[35] https://www.keremcilli.com/gunes-enerjisi-santrali-kurulum-maliyeti-2022/

[36] https://www.forbes.com/home-improvement/solar/cost-of-solar-panels/

[37] https://epdk.gov.tr/Detay/Icerik/3-15589/son-kaynak-tedarik-tarifesi

[38] TAN, Zhimin, FENG, Xiao, et WANG, Yufei. Performance comparison of different heat pumps in low-temperature waste heat recovery. Renewable and Sustainable Energy Reviews, 2021, vol. 152, p. 111634.

[39] Annibaldi, V., Cucchiella, F., De Berardinis, P., Rotilio, M., & Stornelli, V. (2019). Environmental and economic benefits of optimal insulation thickness: A life-cycle cost analysis. Renewable and Sustainable Energy Reviews, 116, 109441

[40] Vieira, F. M., Moura, P. S., & de Almeida, A. T. (2017). Energy storage system for self-consumption of photovoltaic energy in residential zero energy buildings. Renewable energy, 103, 308-320.

[41] Torcellini, P. A., & Crawley, D. B. (2006). Understanding zero-energy buildings. ASHRAE journal, 48(9), 62-69.

Curriculum Vitae

Name Surname : Loic Rebnodji DJANA

Education:

2013–2020 BSc., İzmir Kâtip Çelebi University, Dept. of Materials Science Eng.

2020–2023 MSc., İzmir Kâtip Çelebi University, Dept. of Energy Eng.

Publications:

1. A case study on PV-aided net zero-energy building: the daycare in IKCU