SHAGHAYEGH
OSTOVAR RAVARI

ASSESSMENT OF THE SOLAR PANEL MOUNTING SYSTEMS
WITH ARCHITECTURAL AND ENGINEERING
CONTEXT IN NICOSIA CITY AS A CASE STUDY

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Declaration

I hereby declare that all information, documents, analysis, and results in this thesis have been collected and presented according to the academic rules and ethical guidelines of the Institute of Graduate Studies, Near East University. I also declare that as required by these rules and conduct, I have fully cited and referenced information and data that are not original to this study.

Shaghayegh Ostovar Ravari

14/06/2022

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Shaghayegh Ostovar Ravari

Abstract

Assessment of the Solar Panel Mounting Systems with Architectural and Engineering Context in Nicosia City as a Case Study

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Clean energy production is one of the key priorities of many countries, therefore, the use of renewable energy to generate electricity is growing worldwide. Northern Cyprus has made efforts to lessen reliance on oil products and increase the usage of renewable energy sources. As a result, the usage of solar energy and the installation of PV panels in this area has increased in recent years. This thesis assesses the current state of PV panel mounting systems and related concerns with architectural and engineering context in Nicosia as a case study. In this regard, extensive and accurate data have been collected from five distinct sources including authorities, ministries, stakeholders, and inspections. The data were then analyzed, the current state of PV panel mounting systems was evaluated based on data analysis, and the main weaknesses, major concerns, and critical problems were identified.

64 ETABS models of mounting systems for holding rooftop PV panels were developed, which were used to investigate the effects of factors including beam span length, load resisting system, column arrangement, available roof area, the required distance between arrays, and the orientation of the building to the north on the deflection of the beams of the mounting system, the cost and weight of the mounting systems, and the aesthetics of the building. Alternative mounting systems for the case study were suggested to optimize power generation and minimize the direct and indirect effects of the mounting system on the building and surroundings.

Various standards of rooftop PV panels from certain countries were reviewed, and proposals for improving the standards of rooftop PV panel mounting systems in Northern Cyprus were made to maintain system efficiency and optimal functioning while protecting the safety of systems and individuals.

***Key Words**:* mounting system, Northern Cyprus, PV panels, solar energy, solar panels

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List of Abbreviations

ASCE 7-16: American Society of Civil Engineers: Minimum Design Loads for Buildings and Other Structures

KIB-TEK: Turkish Electricity Authority of Cyprus

PV panel: Photovoltaic panel

TS498: Design Loads for Buildings, Turkish Standard

YEK: Renewable Energy Resources Board

CHAPTER I
Introduction

Energy supply is one of the most pressing concerns for the future of every country and is directly linked to economic growth (Islam et al., 2015). For centuries, electricity has been generated from various non-renewable energy sources which have resulted in air pollution, rising sea levels, increasing global warming rate due to CO_2 emissions, and threatening the quality of life on Earth (Gergelova et al., 2020, Sudimac et al., 2020, Wujek & Sprawka, 2019).

Furthermore, the worldwide rapid run-out of fossil fuel resources and the rising cost of them are other problems of using these energy sources and indicate an urgent need to find effective solutions for the future (Yenen & Fahrioglu, 2013). As a result, considerable efforts are currently being made to identify adequate solutions, with a greater emphasis on alternative energy sources, one of which is the use of renewable energy sources (Okoye & Abbasoğlu, 2013).

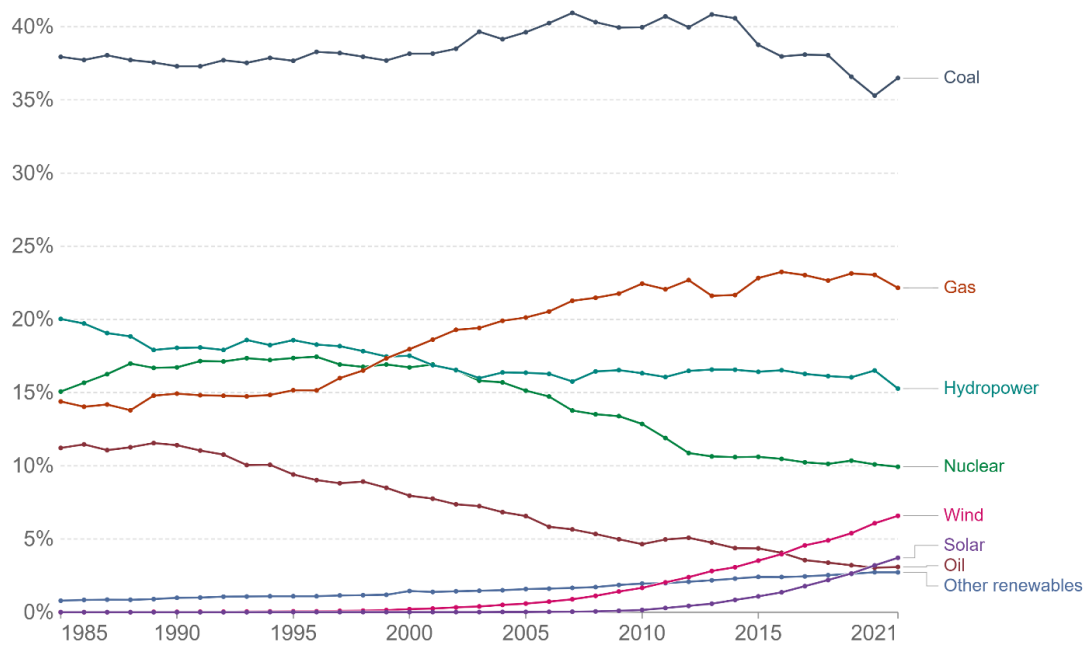
The use of renewable energy sources reduces dependence on non-renewable sources of energy, decreases CO_2 emissions protect the environment, lessen the energy crisis, and reduce utility costs (Bao et al., 2017, Sudimac et al., 2020).

Solar energy is a significant and attractive source of renewable energy around the world. The earth is located 150 million km from the sun and it is estimated that the total energy that reaches the earth's surface is around 1.08×10^{14} kW and the total solar radiation that reaches the earth's surface is 3,400,000 EJ each year. The total annual solar radiation that reaches the earth's surface is more than 7500 times the total annual energy consumption of the world (WEC resources solar, 2022, Kassem, 2019).

In 2021, 36.49% of the global electricity was produced from coal, 3.1% from oil, 22.16% from gas, 9.94% from nuclear, 15.28% from hydropower, 6.59% from wind, 3.72% from solar, and 2.73% from other renewable energy sources (Ritchie et al., 2020). (Figure 1)

Figure 1

Share of Electricity Production by Source in the World (Ritchie et al., 2020)



Energy from the sun is directly converted into electrical energy using photovoltaic (PV) panels (Kassem, 2019). But some considerations have to be made in order to improve the efficiency of PV panels for power generation, including shading analysis. Even shading on a quarter, half, and three-quarters of a solar panel can reduce its efficiency by 33.7%, 45.1%, and 92.6%, respectively. Therefore, the installation site should cause minimal shading on the panels (Kumar & Chandi, 2019).

On the other hand, the installation place should be easily accessible, with a low risk of vandalism and theft at the same time. In addition, land use plans and land costs should be considered (Shapiro, 2012). As a result, finding a suitable location that could give ideal conditions for the installation of solar panels, particularly for household projects, is difficult in many cases. In some countries such as Northern Cyprus, the land limitation is an important challenge, and due to gaining the remaining places, vertical growth takes precedence over lateral growth. Due to all these factors, the roofs of the buildings have become one of the most suitable places for the installation of PV panels in Northern Cyprus and many other regions of the world. In addition to the installation location of PV panels, weather conditions such as the duration of sunlight, ambient temperature, relative humidity, wind speed, and transparency index affect the production of electricity by PV panels. But among the above parameters, the duration

of sunlight is the most critical parameter, because these panels only generate electricity if exposed to direct sunlight, and in cloudy and rainy weather, their effectiveness is significantly reduced (Gonzalez Montoya et al., 2018, Kumar & Chandi, 2019).

As a result, a wide range of variables must be taken into account in order to maximize the efficiency of PV panels. In addition, it should be noted that panels have negative side effects and cause some problems.

Statement of Problem

PV panels are known as an external element for building structures and are installed on new or existing structures. In addition to their advantages, PV panels can cause roof problems that should be taken into account, including structural problems, interruption of roof water flow, and damage to the waterproof layer of the roof. Furthermore, PV panels should be mounted on roofs in a manner that does not detract from the aesthetic of the building, maintain the stability and efficiency of the panels in various weather conditions and under service loads, provide residents with safety, prevent panel damage, prevent glare problems, prevent financial loss, and respect consumer preferences (Bao et al., 2017, Bosman, 2020, Kalogirou, 2015).

Therefore, different countries have provided guidelines or regulations based on the conditions of their country to optimally use the capabilities of solar panels to generate electricity and reduce structural problems, minimize their side effects on surroundings, and ensure the longevity and safety of the structure and residents.

Although power generation using rooftop PV panels has expanded in Northern Cyprus, there is no official regulation or standard for installing rooftop PV panels in this country, other than a few general rules set by some municipalities and the Ministry of Electricity. Therefore, rooftop PV panels are mounted by solar panel installation companies in various shapes and systems, without any structural and architectural supervision, and have recently faced widespread problems. As a result, many architects, structural engineers, and residents complain about the installation of solar panels, especially on roofs, and these issues have even been brought up in various communities and platforms (scientific meetings, parliament, etc.). In this regard, some members of the parliament, the Minister of Economy, and the Minister of Energy have stated that the position, visual appearance, safety, and security of the rooftop PV panels have become increasingly critical and need specific attention. (Figure 2) shows some rooftop PV panels installed in Nicosia, Northern Cyprus.

Figure *2*

Installed Rooftop PV Panels in Nicosia, Northern Cyprus

Based on the reviewed literature, only a few studies have taken into account the architectural and structural features of PV panel mounting systems. However, architectural and structural standards, as well as criteria that ensure optimal performance of solar panels must be followed at the same time. As a result, the installed panels are the most efficient, the installation companies and customers are assured of the strength and stability of PV panels and mounting systems, the beauty of the building is preserved to the greatest extent possible, and financial losses are prevented.

Purpose of the Study

This study assesses the current state of the PV panel mounting systems in Northern Cyprus by gathering extensive and accurate data, in order to identify major weaknesses, key problems, and concerns related to solar panel mounting systems.

Then, mounting systems of PV panels are designed and analyzed for installation on flat roofs in Nicosia, North Cyprus. For this purpose, different parameters are taken into the account such as the height of the building, span length, column arrangement, load resisting system, and the number of panels. The load analysis and structural design are done according to the related structural standards, appropriate angle of panels, aesthetics, landscape, and weather condition of the study area. The procedures are given in ASCE Standard 7-16 (Minimum Design Loads for Buildings and Other Structures) and TS498 (Design Loads for Buildings, Turkish standard) is used to calculate the loads, AISC 360-16 (Specification for Structural Steel Buildings) is followed for designing the steel structure, and ETABS 2015 is used for the modelling of the structure.

On the other hand, one of the solar panel mounting systems in Nicosia, North Cyprus which was installed on a three-storey building and was destroyed twice by wind, is inspected and then modelled by the software, and its stability is examined. In addition, alternative mounting systems are provided for this case and compared in terms of the weight of the mounting systems, aesthetics, and cost of the mounting system.

Standards governing mounting systems of rooftop PV panels in Nicosia, Northern Cyprus are thoroughly examined, and recommendations are made to strengthen guidelines and standards and reduce current problems in this city by reviewing the relevant standards of other countries and considering the local conditions.

Research Questions

The main questions in this study are listed below:

- What are the major weaknesses, problems, and main concerns with solar panel installation systems in Northern Cyprus?
- What are the root causes of problems and weaknesses in PV panel mounting systems and how might these problems be fundamentally resolved?
- Which factors affect the design of rooftop PV panel mounting systems and what parameters should be considered to determine the optimal mounting system?
- Which mounting system is suitable for North Cyprus given the current circumstances?

- What are the requirements that need to be added to the standard governing rooftop PV panel mounting systems in Nicosia, North Cyprus?

Significance of the Study

The findings of the study identify the optimum mounting systems of PV panels on flat roofs in the study area based on the number and size of PV panels, the best tilt angle for PV panels according to geographical conditions, aesthetics, structural standards, and weight of the mounting systems, and cost analysis. In light of the findings, optimal installation structures can be developed to limit damage to PV panels, mounting systems, and roofs as a result of natural disasters. Furthermore, the findings of the study have beneficial effects on reducing the negative effects of mounting systems on buildings and urban environments, improving PV panel performance, and increasing the willingness of residents to use PV panels.

Limitations

This research is limited to PV panel mounting systems on flat roofs. On the other hand, the tilt angle of the panels, wind loads, and seismic loads are taken into account based on the geographical conditions of Nicosia, Northern Cyprus. As a result, the designed mounting systems are suitable for Nicosia, North Cyprus. In order to apply the results of this study to other locations, the tilt angle and the corresponding loads should be determined based on the conditions of the area, and then the structural models should be modified accordingly.

CHAPTER II

Literature Review

This chapter includes prior studies and research on the architectural effects of rooftop solar panels and their mounting systems, the structural effects of rooftop solar panels and related pieces of equipment, the studies conducted on this topic in Northern Cyprus, and the best tilt angle for rooftop PV panels in the study area.

Definition of Terms

Photovoltaic panels

Energy from the sun is directly converted into electrical energy using photovoltaic panels (Kassem, 2019). Photovoltaic panels or PV panels are made up of one or more pre-wired and ready-to-install photovoltaic modules. Photovoltaic modules are composed of linked solar cells that are electrically linked in parallel or series circuits and are used to convert direct solar radiations into electricity (Sağlam, 2010, Tur, 2018).

Different types of PV panels can be classified in several ways, one of which is based on their generation. The materials and efficiency of the PV panels are the focus of the Generation Classification (Wujek & Sprawka, 2019).

- First Generation of PV panels

They are the most common type of PV panels, which are made of monocrystalline silicon or polysilicon and are utilized in typical surroundings, which include monocrystalline PV panels and polycrystalline PV panels.

- Second Generation of PV panels

This generation of PV panels is made of thin-film solar cells of various varieties that are mostly utilized in photovoltaic power plants and facades of buildings, which include thin-film PV cells and amorphous silicon PV cells.

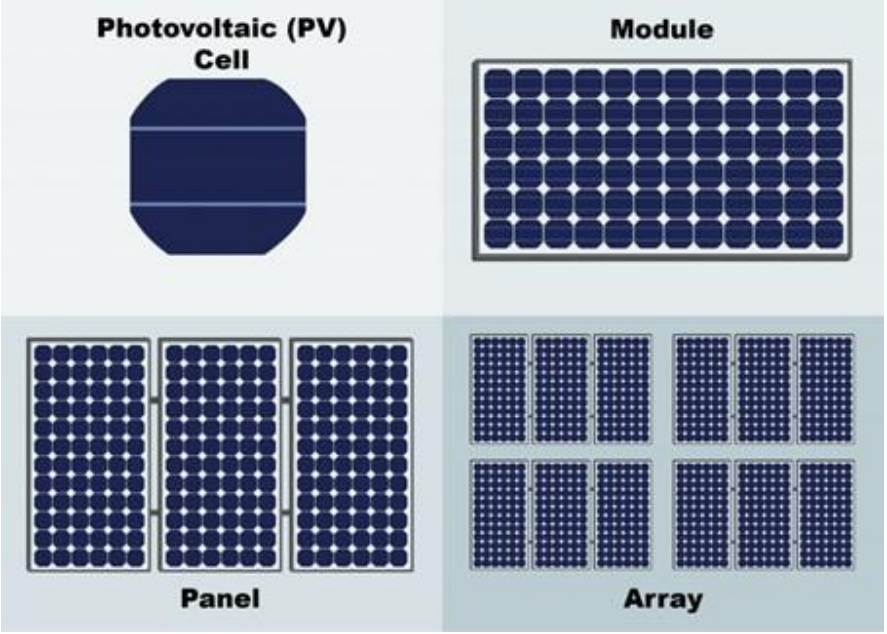
- Third Generation of PV panels

The third generation of PV panels consists of a variety of thin-film technologies, however, the majority of them are still in the research and development

stage, which include biohybrid PV cells, cadmium telluride PV cells, and concentrated PV cells.

Figure 3

Different Parts of Photovoltaic Units (Tur, 2018)



Arrays of photovoltaic panels

Multiple solar panels are electrically linked together to make a larger PV panel system termed an array of PV panels because the energy delivered by a single module of PV panel is insufficient for general usage. Any number of PV panels can be used to build an array of PV panels. The larger arrays of PV panels generate more electricity. (Cells, modules, and arrays, 2022, Sağlam, 2010).

The mounting system of PV panels

Photovoltaic panels require support structures, commonly referred to as mounting systems, to hold them in place at a specific tilt angle and orientation. Mounting systems vary according to the installation location, which are:

- ✓ Roof-mounting

The roofs of buildings provide suitable conditions for mounting PV panels. Arrays of PV panels are installed at the optimum tilt angle on the roof of flat roof buildings, however, if the roof is inclined, a parallel installation of PV panels is done on the roof.

Figure 4

Roof-mounting PV Panels

✓ Building-integrated

Photovoltaic materials that are utilized instead of traditional building materials in portions of the building envelope such as skylights or facades are known as building-integrated photovoltaics. Mounting these photovoltaic materials varies based on the type and location of installation.

Figure 5

Building-integrated PV Panels

- ✓ Ground-mounting

Large-scale solar power facilities are usually built-in open areas with minimal risk of shadows on the panels. PV panels are installed using ground installation systems in a place with the desired tilt angle.

Figure 6

Ground-mounting PV Panels

The tilt angle of PV panels

The collection efficiency of PV panels can be increased by installing them in a direction where the rays of the sun are perpendicular to the panel surface and maximizing the direct sunlight exposure of panels. But this is complicated by the fact that the angle at which the sun appears in the sky changes throughout the day and throughout the year. As a result, the optimal "tilt angle" or "elevation angle" for a PV panel, which describes the vertical angle of PV panels, changes over time.

Furthermore, the installation angle varies based on the latitude of the area. Therefore, each location has an optimal slope angle for the installation of PV panels, which increases the efficiency of PV panels and power generation. Considering the ideal tilt angle significantly increases the efficiency of PV panels. (IFC, 2015).

Building integration

Architectural design, structural design, building systems, and materials must be integrated to achieve the required functional purposes in a well-designed project. Considering the integration concept in a project is a designing strategy that assists to consider the unique characteristics of each project component and look for their potential dual or shared functions. Considering the integration of building systems

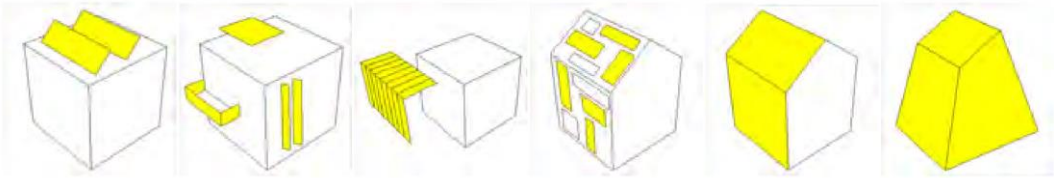
raised some opportunities to increase project performance, but a lack of integration among the architectures, engineers, designers, and builders leads to missed opportunities and additional expenses might be added to the projects (Kalogirou, 2015, Mohammed et al., 2012).

Adding PV panels to a building, especially one that has already been constructed, may compromise the integration of the building, which must be considered during the process of planning, constructing, installing, and operating the panels to increase their efficiency and protect the building's integration.

Based on the condition of the building there are six categories for integration of the PV panels in the building envelope, including added technical elements, added elements with double function, free-standing structure, part of surface composition, complete façade/roof surface, and form optimized for solar energy (Munari Probst et al.,2013). These six categories are shown in (Figure 7).

Figure 7

Integration of the PV Panels in the Building Envelope (Munari Probst et al.,2013)

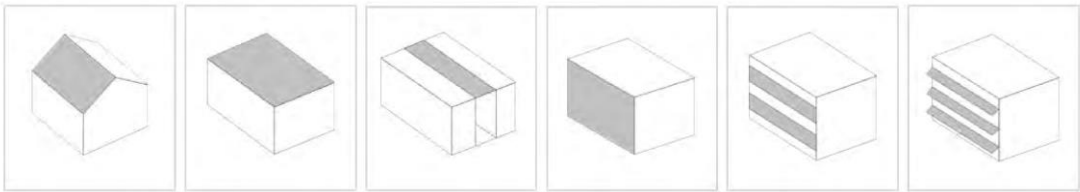


PV panels in the building envelope

PV panels can be used in three different ways in the building envelope including roofs, facades, and external devices. (Figure 8)

Figure 8

PV Panels in the Building Envelope



Each of these types can be used based on the required number of PV panels, standards, local conditions, and building conditions. In this study, flat roofs of residential buildings are considered for the installation of PV panels.

Related Researches

Architectural effects of rooftop solar panels

Bao et al. (2017) conducted two surveys of U.S. residents for their study, with 194 and 350 participants. Detailed consumer preferences for solar panel aesthetics, such as color, surface pattern, frame, and visibility, were studied in the first survey. While the second survey evaluated the relationship between PV panel appearance, functional performance, and cost of the PV panels. According to the results, consumers favored PV panels that match the color of the roof, and also, they were willing to spend more money for less visible rooftop PV panels or PV panels with a better appearance.

Breukel et al. (2016) conducted a survey to determine the relative value of aesthetics compared to other features such as investment costs, repayment period, reliability, and services required by homeowners. The survey received 231 responses. All participants stated that aesthetics is an important feature and 60% of them consider the aesthetics of PV panels as the key factor, thus if it is not possible to select PV panels with a nice appearance, they do not use PV panels.

Petrovich et al. (2019) conducted a survey of 408 Swiss homeowners in two different sections. The first part was about the aesthetics of PV panels and the second part was about their budget status for PV panels. According to the results, 69% of participants stated that the aesthetic aspects of PV panels are the key feature and they pay more for beauty and visual appeal, 5% of participants do not want to use them because PV panels are not attractive and they do not match the exterior of buildings, and other future adopters of PV panels have stated that they are not willing to pay more for the aesthetics of PV panels and budget is a critical matter. These results indicate that a significant proportion of respondents are sensitive to the appearance of rooftop PV panels and the intention to install rooftop PV panels correlates with their visual attractiveness.

Lu et al. (2018) identified the effects of PV panels on the landscape using the visual Q methodology in six types of urban land use, one of which was the rooftop. Photovoltaic system harmony with the environment, innovative design, generating electricity, the height of installation, and social benefits were the effects of PV panels

on the landscape that have controlled in each urban land use. According to the results, photovoltaic applications on roofs are more desirable due to lower visibility and the risk of glare. However, rooftop PV panel landscapes should be aesthetically compatible with the surroundings, and the color, shape, and height of PV panels should be given special attention.

Idowu et al, (2019) investigated the relationship between the energy production potentials of rooftop PV panels and the aesthetic quality of the building. For this experimental research project, a dormitory building at the Modibbo Adama University of Technology, Yola was simulated. Then, 12 different models of arrangements and surface coverage of rooftop PV panels were prepared for the building, and they were rated by 140 respondents in four categories. The PV panels on the roof were contrasted and arranged according to the architectural concepts of balance and symmetry in relation to other building elements. To assess the responses, the mean and frequency of rankings within and among respondent groups were computed. To investigate the relationship between aesthetic attractiveness and the area covered by solar photovoltaic panels on a roof, Spearman's rank-order correlation coefficient was used.

The structural aspect of rooftop solar panels

Naeiji et al. (2017) examined wind load effects on PV panels installed on different types of residential building roofs. Various geometric properties, including the tilt angle of the PV panels, clearance distance which is the distance between the bottom edge of the PV panel and the roof surface, the height of the residential building, and the type of the roof, were examined to evaluate their effects on wind loads on PV panels. According to the findings of this study, the inclination angle of PV panels and the type of roof are the most critical parameters that affect the wind load on rooftop PV panels, while the effects of clearance distance and height of the building are in the next order.

A PV panel mounting system and its main design parameters, calculation method, and finite element analysis were performed by SAP2000 and a case study on PV panel installation systems in Turkey was evaluated by Cigdem (2020). Loads including dead load, snow load, seismic load, and wind load were determined for the PV panel mounting system in accordance with the Turkish Earthquake Code (TEC) and TS498.

Mihailidis et al. (2009) considered two different approaches to designing solar panel support structures, which include a fixed system and an adjustable system that has mechanisms for automatic rotation around two axes. To determine the load distribution on the PV panel, a simple CFD model was developed using ANSA as the preprocessor and ANSYS-CFX as the solver. The loads acting on the surface of PV panels were calculated using EUROCODE 1. For analyzing the structure, an FE model was created using ANSA as the preprocessor. Loads were applied to the model and MSC Nastran was used as the solver. Critical points were identified and redesigned.

Abiola-Ogedengbe et al. (2015) conducted a study to examine the distribution and effects of wind load on ground-mounted PV panels in an experimental setting. It involves a quantitative analysis of the wind load distribution on the PV panel and a parametric study to assess the impact of different variables including wind exposure and slope of the panels. Besides, the load effects on the model and its horizontal equivalent surface were compared. A wind tunnel test in four different wind directions was conducted and the pressure field on the top and bottom edge of a PV panel array made up of 24 PV panels was investigated.

Gavrila et al. (2017) performed virtual modelling and finite element analysis for an installation structure used for fixed PV panels or collectors on roofs. In general, solar panel manufacturers use fixed installation systems to install solar panels that consider the characteristics of the solar panel more than the desired roof conditions. However, the classic roofs of houses are covered with ceramic tiles and do not match the kit of solar panel installation systems, which in most cases leads to the breaking of tiles and the infiltration of rainwater into the structure. In this study, modelling was performed using CATIA software and metallic clips holding solar panels and ceramic tiles were considered the main parts involved in the stabilization of the solar panel on the roof. The wooden roof structure on which the entire solar panel system rests was considered rigid. For analysis, the force applied to the metal clamps included the weight of the panels, frames, fixed kits, and the weight of wet snow.

Rohit et. al. (2020) sought to design the structural components of a solar panel mounting system connected to a water pump. In this study, the adaptive design of members and theoretical checking of each member in terms of safety, strength, and optimization of panel members were performed. Modelling was performed with different materials including aluminum, galvanized iron, steel, posMAC. NSYS and

CFD were used for analysis, and Solidwork was used for modelling. The weight of the panels and horizontal wind with a constant velocity were considered in this study.

Naeiji et al. (2015) conducted a study for developing a large-scale model for testing solar panels installed on residential buildings in the Wall of Wind (WOW) facility, evaluating wind pressures on solar panels installed on low-rise residential buildings, and investigating the effect of changes in roof distance, slope angle, and the height of the building in terms of wind loads for flat, gable and hip roof buildings. For these purposes, the effects of wind load on the PV system were investigated by conducting large-scale pilot experiments at the WOW facility of the International University of Florida. Models with variable geometric parameters including roof type, building height, roof-to-plate distance, and slope angle were tested. Large-scale experiments make it possible to model small distances such as the gap between the PV panel and the roof surface and measure pressure at multiple locations on the screen.

An experimental study was conducted by Alrawashdeh and Stathopoulos (2020) to investigate the effect of wind loads on rooftop PV panels while the upstream simulation conditions were constant and unchanged. Therefore, models with different geometric scales such as 1:200, 1:100, and 1:50 were designed in the simulated boundary layer flow to evaluate the effect of size violation of the experimental model of roof PV panels under wind pressure. The models were tested in the atmospheric boundary layer wind tunnel.

Related researches in Northern Cyprus

Damdelen and Şeker (2020) prepared a study to specify the ideal solar energy system for the climatic and economic conditions of Northern Cyprus and also to persuade people to invest in and use solar energy. This research was conducted based on a qualitative method to evaluate the strengths and weaknesses of PV models. The basic principles and permissions of renewable energy regulations, application of the energy produced from renewable energy sources, the implementation of policies and procedures audit and administrative sanctions, environmental, economic, market structure, strategy, and regulatory framework for PV panels were investigated in Northern Cyprus.

Okoye and Abbasoğlu (2013) investigated the technological potential of the photovoltaic system as an alternative to fossil fuels for power generation in Northern Cyprus through an experimental study in which two 100Wp PV systems were mounted

on the roof of the Business Faculty of the Cyprus International University. The tilt angle of the fixed supporting system was 36 degrees, while the dual-axis solar tracking system tracked the sun's path using a solar tracker with satellite control. The systems measured solar radiation, local energy output, and power generation. Data on local power generation, output power, and solar radiation of the region were collected every 5 minutes for 12 months from both systems by the system software. These data were analyzed to determine the average energy production, average power, monthly solar radiation, and average duration of solar radiation for both systems. Finally, a comparison was made between the two systems in terms of power generation capability and power output.

Kassem et al. (2020) presented a study and obtained average temperature, global monthly solar radiation, sunshine, and relative humidity from the Meteorological Department and satellite imagery database for five different sites in Northern Cyprus. The data were statistically analyzed and the form of distribution functions was chosen based on skewness and kurtosis values. A detailed and integrated feasibility study of a 100MW grid-connected PV plant project was carried out in the selected areas, which causes a reduction in electricity tariffs and greenhouse gas emissions. In terms of energy efficiency, greenhouse gas emissions, and cost analysis, RETScreen Expert software was utilized to perform a feasibility analysis for the optimal location to develop a 100MW grid-connected PV facility.

A study was performed by Al Zoubi (2019) to find out students' views on renewable energy technologies and their benefits in Northern Cyprus. A multiple-choice questionnaire was developed to assess the views and level of knowledge of post-graduate students. The findings indicate that majority of students were aware of renewable energy technologies including wind and solar and were interested in using them in Northern Cyprus to produce electricity. Furthermore, the Weibull distribution function was used to investigate wind characteristics and the availability of wind energy for three urban areas in Northern Cyprus. The findings show that Famagusta is the most suitable place to use wind energy to generate electricity among the urban areas of Famagusta Nicosia, and Girne. In addition, the Logistic Distribution Function was used for analyzing global solar radiation over time in these areas. For these purposes, Photovoltaic Geographical Information System (PVGIS) simulation tool

and Clean Energy Management Software (RETScreen) were used in this study. The analysis shows that the proposed PV systems work efficiently in all study areas.

Hastunç and Tekbıyık-Ersoy (2018) used RETscreen analysis to install 4.85 kW rooftop photovoltaic systems in Nicosia, Morphou, and Dipkarpaz. The study aimed to determine whether the installations were financially viable. According to the analysis, Morphou had the most feasible results. MATLAB simulation was performed to determine the optimal number of installations in each city in order to optimize the total electricity exported to the network, taking into account the realistic constraints. According to RETscreen, the city with the most possible results was Morphou, with a simple repayment period of 6.7 years and a net present value of € 816. Nicosia was the worst case, with a repayment period of 7.2 years and a net present value of € 216. Because Morphou has less population and greater potential than Nicosia and Dipkarpaz, its distribution percentage is higher. It should be noted that in this report, the analyzes were only theoretical.

Abdulmajid (2020) conducted a study to design a solar PV system for a single-family home in Güzelyurt, Northern Cyprus. Descriptive analysis was carried out in this study by collecting data related to the research topic from books, periodicals, journals, and some specialized web pages, and a 1kW grid/grid-off connected PV system was evaluated technically and economically. In order to evaluate the economic and energy efficiency of PV panel systems for a single-family home, RETScreen software was utilized. RETScreen analysis was performed in four steps: facility type selection, energy analysis, emissions analysis, and financial analysis. According to the findings, the PV system is an excellent way to minimize fuel usage and greenhouse gas emissions in the chosen area. According to the study, the average reduction in diesel fuel for electricity generation is about 30 percent per year. In addition, this is a new method of architectural formation that affects the overall shape of the house, exterior, and interior spaces, color, and texture that expresses modernity and refinement.

Babatunde et al. (2018) examined the output of PV panel systems subjected to dust, mounted with various tilt angles and different orientations, by comparing one-year measured data, simulations, and analytical calculations. As a case study, the output of five separate PV installations with a total capacity of 1280 kWp mounted at Cyprus International University in Northern Cyprus was examined. Three mounting

methods were used to install the PV plant in five separate locations around campus. The impacts of dust and cleaning on the output of PV systems were investigated. Besides, the simulation results were compared with the measured data from the mounted PV panels. Calculations of electricity generation reveal that the mathematical model is more accurate than simulation and may be used to collect solar radiation by PV panels with minimal errors.

Rabbani (2018) conducted a study to evaluate the design and installation of a residential grid-connected solar photovoltaic system in terms of power, size, and cost. The solar system was simulated using the technical engineering program PVsyst V5.74, and the overall output of the PV system was evaluated for a medium-sized household in Lapta, Northern Cyprus over a year. The results show that this system is very efficient, with a performance ratio of 78% and a return on investment of about 8 years for a typical home installation in Northern Cyprus. Due to losses in the PV system, 22% of the solar energy that falls on PV panels is not converted into usable energy.

Yarmohammadi (2013) worked on a study to highlight the basic characteristics of PV panels, such as different types of PV modules for buildings, construction methods, the orientation of PV panels on buildings, classification and characteristics of PV panels, and the effects of weather conditions on the efficiency of PV panels. In this study, suitability, cost, economic aspects, and current approaches of PV panels were investigated using a qualitative research method at both international and Northern Cyprus levels. The study also looked at the overall efficiency and sustainability of PV panels due to their correlation with structures.

Ouria and Sevinc (2018) examined the use of solar energy in Famagusta, Northern Cyprus. The potential of solar energy for the city was calculated using both climatic and geographic variables, and then the possibility of using solar energy in Famagusta's Social Housing Complex (SHC) district was examined. Duffie Beckman and Stephenson's cousin methods were employed to evaluate the effective parameters of solar energy, such as weather conditions, radiation types, geographical parameters, orientation techniques, landscape analysis, and height-to-width ratio (H/W). Using the Ladybug for Rhino and MS Excel software programs, the amount of solar radiation for horizontal, vertical, and inclined surfaces of blocks and routes in SHC was evaluated.

Erciyas (2014) investigated the sustainability of the installation of solar power plants in Northern Cyprus, as well as their potential environmental and economic benefits. Solar capacity in this area is quite high when compared to other renewable energy sources including wind, according to the Metenorm V6 (MN6) measurement program. According to the MN6 program, in the Dikmen area in Northern Cyprus, 2000 kWh/m^2 of global solar radiation reaches surfaces with a slope of 25 to 35 degrees per year. In addition, an emission study was carried out for traditional power plants using fuel oil-fired in Northern Cyprus. For this purpose, the mass balance analysis method was used to calculate real greenhouse gas emissions and other harmful emissions based on the percentage of the elemental weight of fuel oil No. 6 used in thermal power plants in Northern Cyprus. EPA emission factors were then used to compare emissions. Specific fuel consumption of reciprocating diesel engines and steam turbine power plants was determined using the operating values of the Teknecik and Kalecik power plants. A life cycle cost analysis for the Serhatkoy PV power plant was also conducted, revealing that the savings-to-investment ratio is greater than 1, and concluded that it is economically feasible.

Ogbeba and Hoskara (2019) suggested strategies to increase the comfort of buildings using photovoltaic panels and their shading capability in residential buildings. An empirical investigation was undertaken in this study on the usage of PV panels as a shading system in a typical single-family home in Famagusta, Northern Cyprus, using simulation. In this study, PV integrated shading is proposed as an alternative to reinforced concrete, which is a common building material for shading systems. According to the findings, the use of PVSDs strategically for openings facing east, west, and south saves energy usage by about 50% during three peak months of the year. PVSDs lower energy usage by 400 kWh over the course of the year and boost building comfort by up to 20%. PVSDs utilized as a 0-degree shading system can provide up to 2800 watts, enough to cover up to 50% of a family's electrical needs.

Kassem et. al. (2019) used the Weibull distribution function to examine the available wind energy for the three regions of Northern Cyprus. Furthermore, the efficiency of rooftop PV panels for residential structures was assessed in three different locations. The performance of the 6.4 kWp grid-connected rooftop PV system was simulated and tested using PVGIS, PV*SOL, and PVWatts. This study investigated the energy production, performance ratio, and capacity factor of PV

systems. Besides, a cost-benefit analysis of renewable energy systems in three urban areas was evaluated. As a result, a small-scale grid-connected solar/wind system was proposed and built that could generate electricity with a high percentage of clean energy, and the proposed PV system projects have great potential in the study areas. Furthermore, compared to wind systems, the proposed PV system is the most cost-effective option for generating electricity due to its low electricity cost and ability to repay the initial investment.

Optimal tilt angle in the study area

Abdulsalam and Alibaba (2019) determined the optimal tilt angles for PV panels in Famagusta, Cyprus. PV simulation software was utilized to estimate average solar radiation at various tilt angles in this study. The average angle for three seasons was determined using this simulated data. Adjusting the PV system with the best tilt angle for the entire year significantly increases energy production. According to the analysis, the tilt angle of photovoltaic panels varies depending on the location, weather conditions, and solar radiation. The ideal slope angle in Cyprus is 20° in summer and 50° in winter. However, the optimal tilt angle is between 28 and 30°. In addition, it should be noted that PV panels should be installed facing south in the northern hemisphere.

Darhmaoui and Lahjouji (2013) developed a computer program based on a mathematical model to determine the ideal tilt angle to increase the total amount of sunlight on the sloping surface of the PV panels as much as possible. For this purpose, global daily solar radiation data over four years were collected on the horizontal surface in 35 different locations in different Mediterranean countries, and the program considered the south orientation of the collectors and determined the tilt angle that has the maximum collection of solar radiation in this region. Then regression analysis based on the results of the computer simulations was conducted. In addition, linear and quadratic models were developed to determine the relationship between the optimal annual tilt angle that maximizes the collection of solar radiation in this region and the latitude of the site. The results of quadratic regression had a high prediction accuracy of over 99.87%. Nicosia, Cyprus was one of the 35 regions covered in this paper and according to the results of this study, the ideal tilt angle to maximize solar radiation collection is 34.1°.

Abdallah et al. (2020) determined the tilt angle and azimuth angles of PV panels, which have a great impact on the output of photovoltaic panels for all countries by the Photovoltaic Geographical Information System (PVGIS). In addition, the annual and average daily solar radiation was calculated on inclined and directional panels. In order to analyze and optimize power generation by PV panels, PVGIS has been used to develop an artificial neural network model that can be utilized for an embedded system or an online system. This model is accurate and efficient for predicting the optimal tilt angle and azimuth angle of PV panels around the world. The optimal orientation of PV panels in the northern hemisphere is to the south and in the southern hemisphere is to the north. In general, with increasing latitude, the optimal tilt angle also increases. Based on the results of this study, the optimal tilt angle for PV panels in Nicosia, Cyprus is 31°.

Adedeji et. al. (2014) investigated the effect of tilt angle and orientation of solar panels on their efficiency and evaluated the optimum tilt angle of a PV system in Nicosia, Northern Cyprus. Tilt angle is site-specific; therefore, it should be determined for each installation site. This study provides monthly, seasonal, and yearly optimal tilt angles for PV panels in Nicosia, Northern Cyprus based on the equations of solar geometry. In addition, PVSYST simulation software was used to validate the results and examine the efficiency of a PV panel system by changing the tilt and azimuth angles. The optimum tilt angle of a PV panel system is changed by changing the direction of the sun. Therefore, the best angle for installing solar panels on different days of each month was determined using the equations of solar geometry, and then the monthly average was calculated for each month. Then, the average optimal slope angle for each season was calculated using monthly averages, and finally, the average optimal tilt angle of a year was determined using seasonal averages. The results of this study showed that the optimal tilt angle in Nicosia, Northern Cyprus is 32 while the panels are oriented to the south.

Kassem et. al. (2019) simulated the performance of different PV technologies for installation at Near East University. In this study, PVGIS was used to collect and analyze data and compare the performance of different PV technologies. Performance ratio, energy efficiency, capacity factor, energy cost, and optimal tilt angle were evaluated for a 110kW PV system. In this study, the tilt angle was varied from 20° to 43° to evaluate the changes in energy production and solar radiation for each system

and to investigate the optimal slope angle. According to the results of this study, the best tilt and azimuth angles for all PV systems in this place are 31° and 0°, respectively.

The Solar Atlas World Map contains a collection of global, regional, and national GIS data layers and poster maps, and is a reliable data source that can be used to assess the potential usage of solar energy in a variety of locations and to provide some data, such as global horizontal irradiation, direct normal irradiation, diffuse horizontal irradiation, global tilted irradiation at the optimum angle, and best tilt angle of PV modules. Based on this atlas, the ideal tilt angle for installing PV panels in Nicosia, Northern Cyprus is 31° (Solargis, 2022)

CHAPTER III
Methodology

The research method is divided into four stages. The first step is to obtain reliable, accurate, and up-to-date data from various sources on the desired subject and analyze them to identify and clarify problems. The second step is to provide mounting system models for rooftop PV panels using the collected data and considering the current issues and taking into account the relevant standards and different variables which lead to the design of optimum mounting systems for rooftop PV panels in the study area.

The third step is to inspect one of the worst mounting systems of rooftop PV panels in Nicosia, Northern Cyprus, model the mounting system with software, assess its current status, and present some alternative mounting systems by considering the standard points and the roof conditions.

The fourth step is to review the standards related to the mounting system of PV panels that are followed in the world and in Nicosia, North Cyprus, and to provide recommendations to improve the existing conditions of rooftop PV panels in Nicosia, North Cyprus.

Study Area

Nicosia (Lefkosa), Northern Cyprus has been selected as the study area for this thesis. Cyprus is the third largest island in the Mediterranean region, located 33 degrees east of Greenwich and 35 degrees north of the Equator. Cyprus has a typical Mediterranean climate with typical seasonal changes: summers are hot and dry, lasting from May to September, while winters are usually rainy from November to mid-March. Autumn and spring are short seasons that separate summer and winter.

Nicosia has been the capital of Cyprus since the 11th century BC and is located almost in the center of the island. The island of Cyprus has been divided into Greek and Turkish parts since 1974, and Nicosia has been the capital of both parts of Cyprus since then (Delipetrou, 2008).

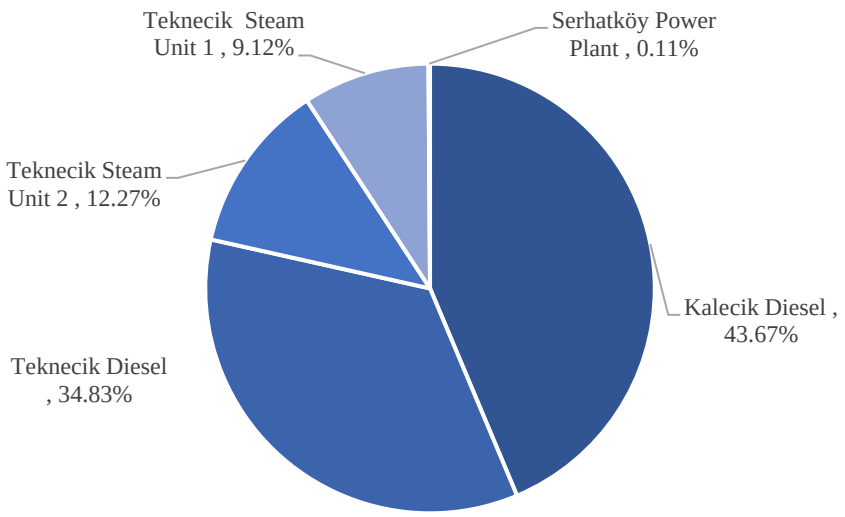
Energy production in Northern Cyprus

In the north part of the island, the Turkish Electricity Authority of Cyprus (KIB-TEK) is responsible for supplying electricity. Although Northern Cyprus has

attempted to reduce its reliance on oil products for generating electricity in recent years, power generation still relies mostly on non-renewable energy sources. Northern Cyprus imports oil products, which resulted in dependency, energy crises, a volatile energy market, and rising electricity prices. KIB-TEK generates the required electricity in Northern Cyprus using five power plants. Kalecik Diesel with 43.67% has the largest share of electricity generation among power plants, it is followed by Teknecik Diesel with 34.83%, Teknecik Steam Unit No. 2 with 12.27%, and Teknecik Steam Unit No. 1 with 9.12%. Serhatköy power plant uses solar energy to generate electricity and has a small share of electricity generation with 0.11% (Okoye & Abbasoğlu, 2013, Yenen & Fahrioglu, 2013). The share of electricity generation of each power plant is shown in (Figure 9).

Figure 9

Share of Electricity Generation of Each Power Plant in Northern Cyprus (Kassem et al. 2019)

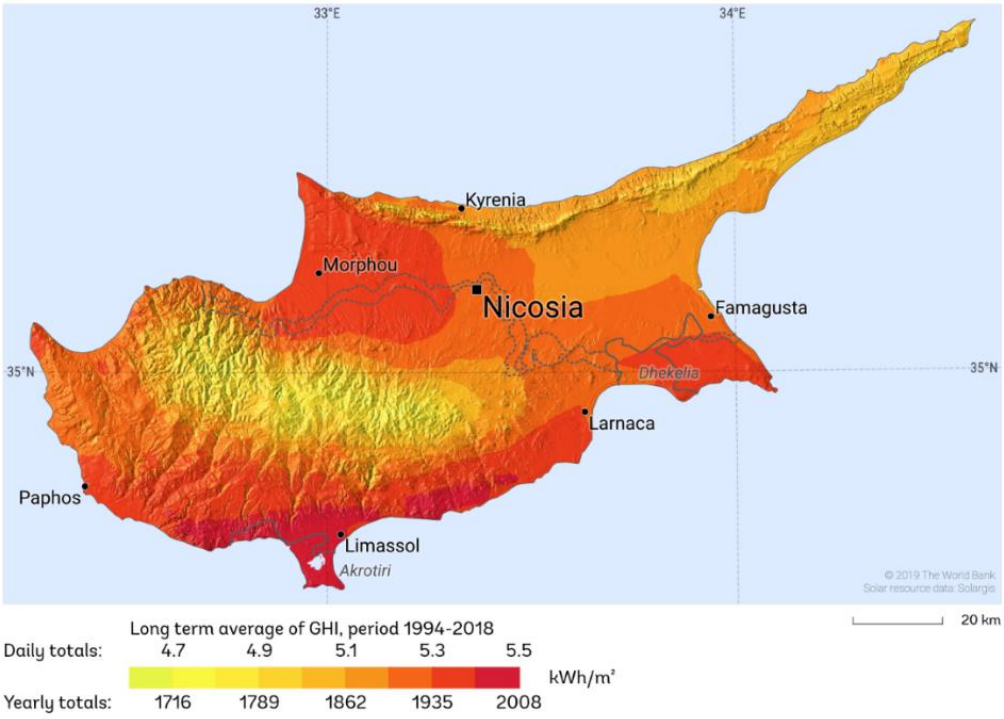


Potential of using solar energy in the study area

Cyprus has approximately 300 to 320 sunny days, receives between 2,700 and 3,500 hours of sunshine per year, and its daily average global horizontal irradiation varies from 4.80 kWh/m^2 to 5.44 kWh/m^2 (Mustafa, 2020, Okoye & Abbasoğlu, 2013). Therefore, Cyprus has exceptional conditions and substantial potential for the use of solar energy due to its unique geographical location.

Figure 10

Global Horizontal Irradiation in Cyprus (Solargis, 2022)



Seismicity of Cyprus

The maps below show that the island of Cyprus is located roughly on the border between the Eurasian Plate and the African Plate. The African Plate moves north-north-eastward relative to the Eurasian Plate. On the other hand, the Arabian plate moves northward, but at a higher rate than the African Plate. Anatolian sub-plate is forced to move west due to the collision of both the African and Arabic Plates with the Eurasian plate (Cagnan & Tanircan, 2010).

Due to the geographical location of Cyprus and the movement of the plates in this region, the island has been affected by many devastating earthquakes (Cagnan & Tanircan, 2010). But in general, the island is mainly affected by shallow and moderate earthquakes that occur along the Cyprus arc and the Dead Sea fault zone. Therefore, the western, southern, and central regions of Cyprus are the most seismically active areas due to their proximity to faults. However strong earthquakes that occur in these parts of the island are felt throughout the island (Kythreoti, & Pilakoutas, 2000, Papadimitriou & Karakostas, 2006).

Figure 11

The Principle Tectonic Elements of The Northeastern Mediterranean Region (Cagnan & Tanircan, 2010)

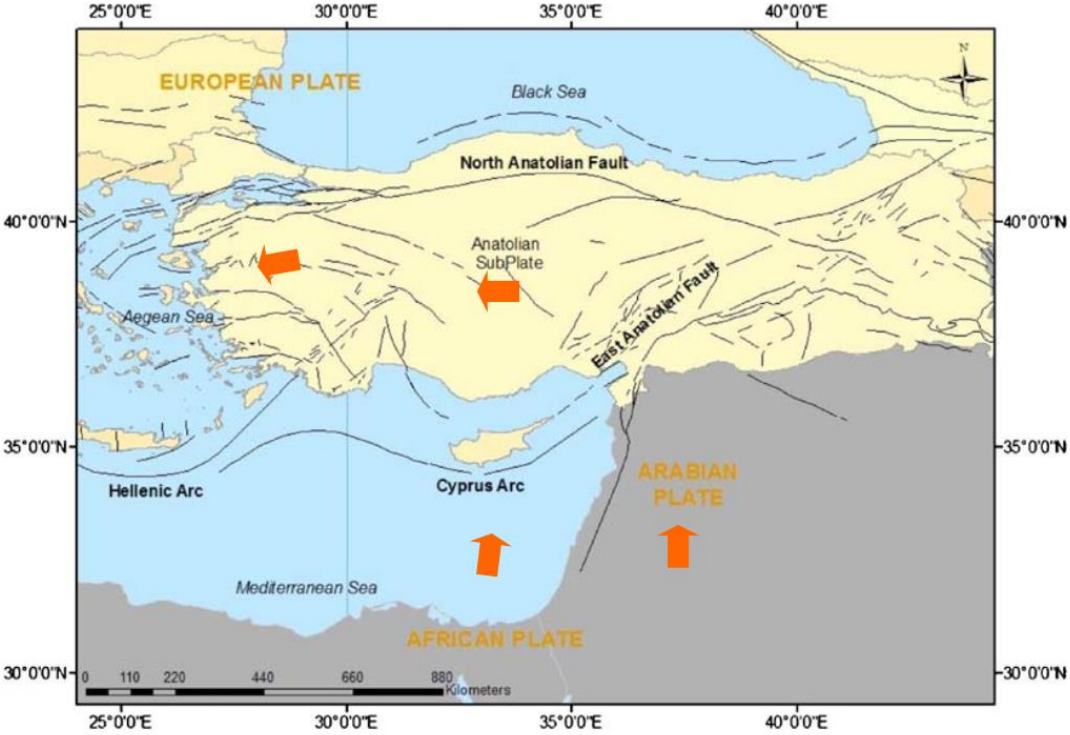
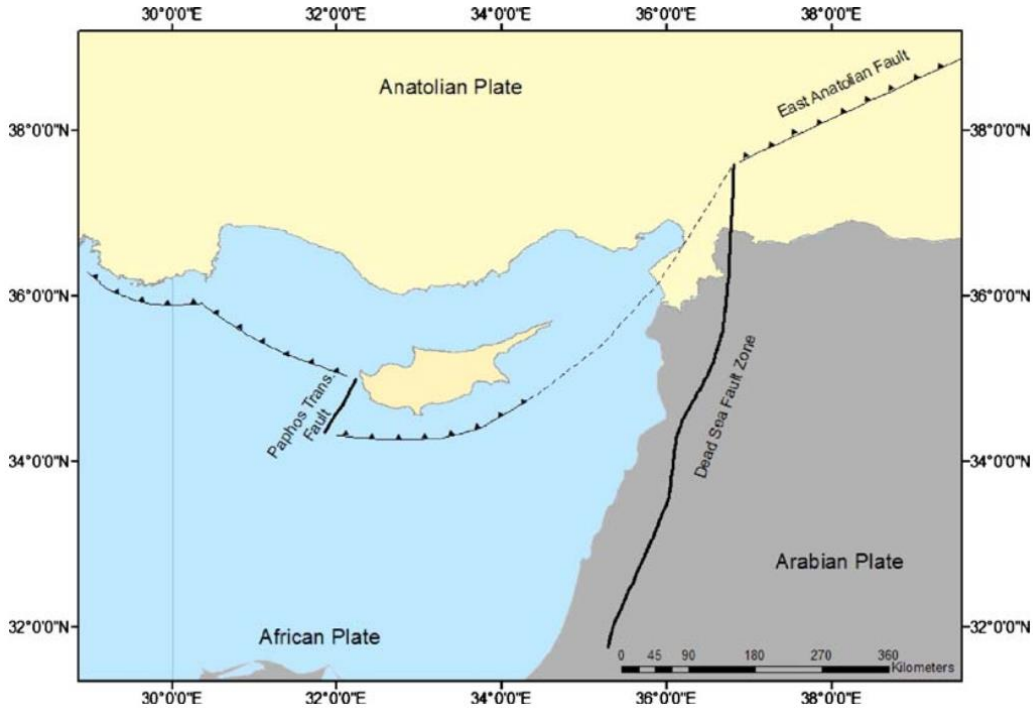


Figure 12

Proposed Plate Boundary in The Eastern Mediterranean Area (Cagnan & Tanircan, 2010)



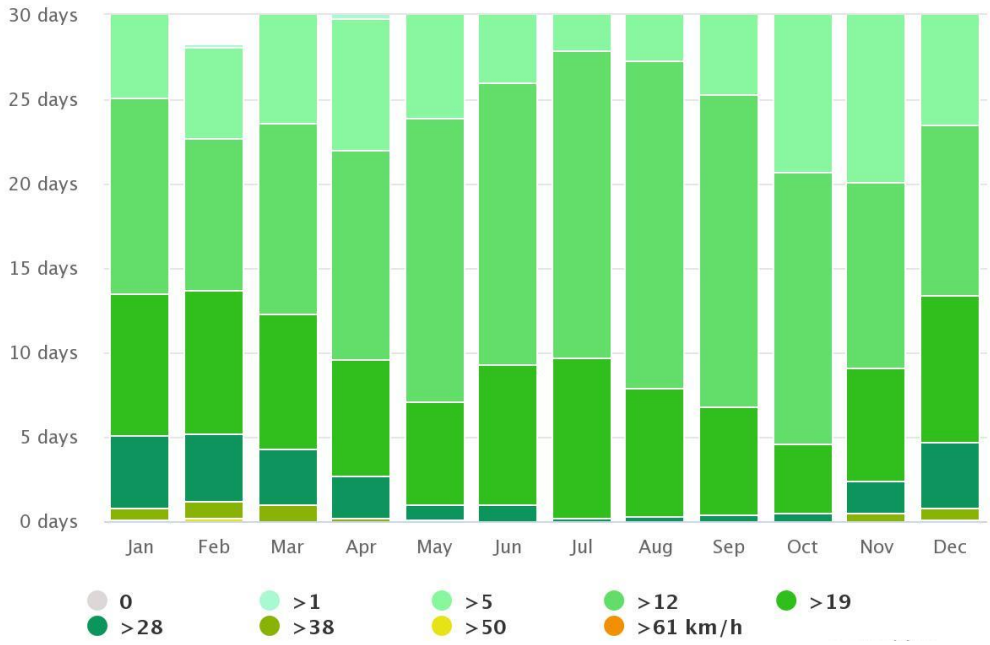
Wind situation in Cyprus

Cyprus is surrounded by the Mediterranean Sea and climate change has affected this island over the last decades with a wide range of consequences, such as changes in rainfall levels, changes in temperatures, and extreme weather events such as hurricanes, which have affected the average wind speed in this island. Besides, tornadoes are rare occurrences in the Mediterranean, however, their number and strength have increased in recent years due to climate change and global warming. Climate change has had many direct and indirect effects, one of which is the change in wind speed and wind loads on buildings, structures, and equipment, which has led to many injuries, fatalities, and great economic losses. Consequently, the consideration of wind loads in the design of any type of structure has become more important (Kassem, 2019, Özerim, 2020, Agencies, 2020, NCN, 2020)

(Figure 13) shows the number of days per month during which wind speed reached a certain speed in 2021, in Nicosia, Northern Cyprus.

Figure 13

Average Daily Wind Speed Per Month in Nicosia, Northern Cyprus (Michaelaschludecker. 2021)

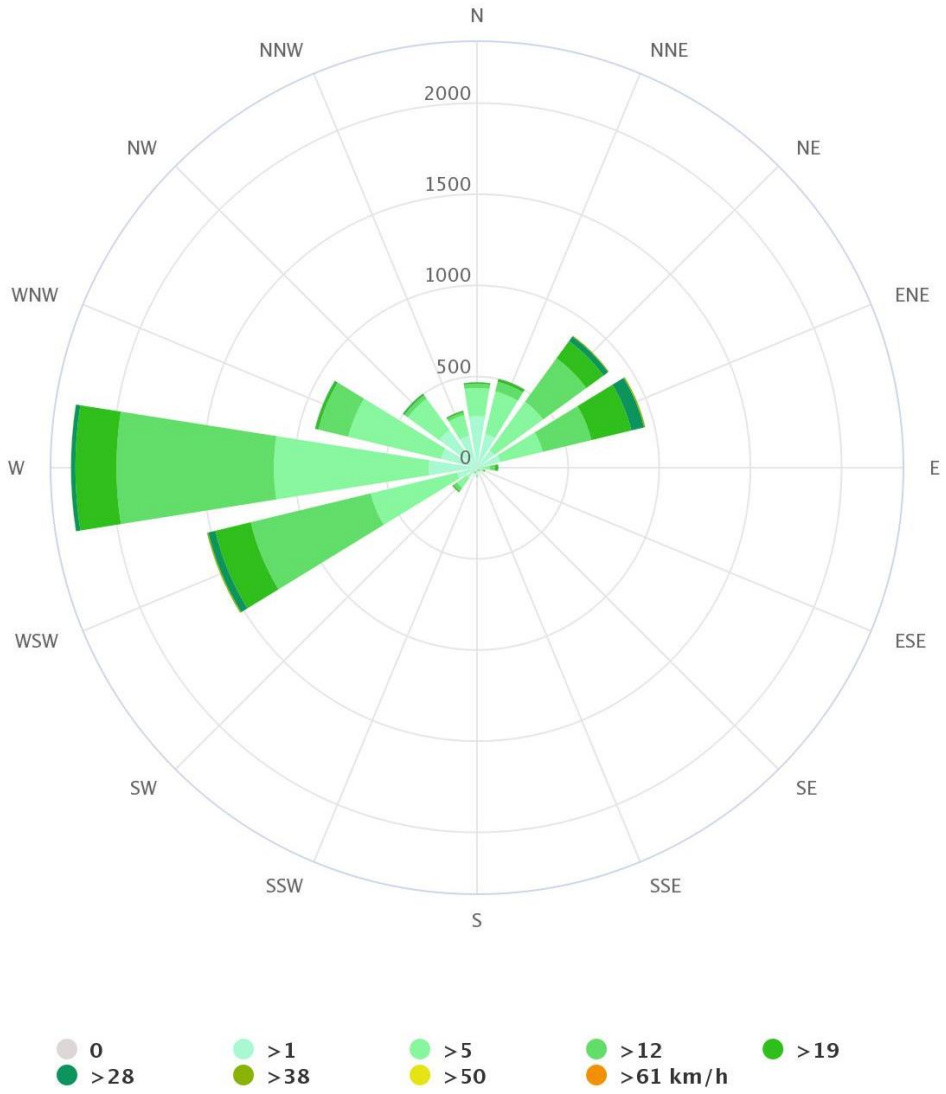


In addition, (Figure 14) is the wind rose of Nicosia, North Cyprus which shows how many hours a year the wind blows in the indicated direction. As shown, the

majority of winds in Nicosia blow from west to east and west-southwest to east-northeast (Michaelaschludecker. 2021).

Figure 14

Wind Rose of Nicosia, North Cyprus (Michaelaschludecker. 2021)



Data Collection Procedure

The first and essential step in the study is to collect comprehensive, reliable, accurate, and up-to-date data, diagnose problems and identify the main one.

The data required for this study are collected in a categorized manner from five distinct sources through documents, interviews with stakeholders and relevant authorities, and site inspections of some mounting systems of PV panels. Data sources and data collection tools are described below:

A member of YEK (Renewable Energy Resources Board)

A member of YEK is interviewed and some questions are asked about the rules and standards for installing PV panels, the relevant guidelines, the terms and conditions of authorized roofs for PV panel installation, inspections, and monitoring procedures for installing rooftop PV panels.

KIB-TEK (Turkish Electricity Authority of Cyprus)

Some documents are collected from KIB-TEK regarding the number of Low Voltage (LV) PV panel projects, most of which are installed on roofs, the number of Medium Voltage (MV) PV panel projects, and the electricity produced by PV panel projects in Northern Cyprus. These data are annual and cover the years 2014 to 2020.

PV panel installation companies

Some questions are asked from PV panel installation companies in Nicosia, Northern Cyprus. The questions are divided into seven categories, which are listed below:

- The background of the company
- Considerations for installing rooftop PV panels (available roof area, shading issues, locations of the project, PV arrays and other equipment, size of electrical services, aesthetics and beauty, roof condition, building type, roof orientation, roof age, proximity to other equipment, environmental factors, codes and local requirements, risk assessment, accessibility, and working spaces)
- Information on the mounting system (load resisting system, materials, etc.)
- Mounting system calculations and analysis methods (considered design loads, loads calculation methods, and structural analysis methods)
- Shading analysis
- Architectural and aesthetic considerations
- Guidelines and standards

Users of PV panels

Thirty-two users of PV panels in Nicosia, Northern Cyprus are asked questions in three different areas, including:

- Mounting system problems

- Side effects of mounting systems
- User concerns

Site inspection and taking photos

Field observations of 50 projects and detailed inspections of 10 projects are conducted, and several photographs are taken from different parts of the mounting systems of PV panels.

Data Analysis Procedure

After collecting the desired data from relevant sources and categorizing them, the growth rate of PV panel installation and the rise in electricity generated by PV panels between 2014 and 2020 are investigated. Then, the effective factors in increasing the tendency to install PV panels are examined based on the interviewers with a member of YEK, PV panel installation companies, and users.

In the next step, the results of interviews with PV panel installation companies are reviewed and according to the interviews and site inspections, the main weaknesses and major problems in the procedure of designing and installing mounting systems of PV panels, mounting system calculations, analysis methods, and architectural and aesthetic considerations are investigated.

Lastly, the results of interviews with PV panel users are reviewed and user concerns, mounting system issues, and side effects of mounting systems are categorized based on the users' point of view.

Besides, the data collected from inspections and measurements of the case study are used to model the mounting system with software, examine the current status of the mounting system, and also propose some alternative mounting systems to solve current problems of the mounting system and provide an optimal mounting system for the building.

Description and Assumptions of the Models

General models (32 Models)

In this study, 32 different general models of rooftop PV panel mounting systems have been developed to investigate the effects of some variables on the mounting systems and beam deflections. These models are developed for installation on flat roofs with the same steel frame section as "SHS 4X4-0.26". Building height,

load resisting system, span length, and column arrangement are variables that have been considered to control their impact on beam deflection, which are described below:

The number of storeys. PV panels can be installed on buildings of different heights. In the study area (Nicosia, Northern Cyprus) a 3-storey building is a typical height for buildings, especially residential buildings. On the other hand, according to the data collected in this study, the tallest building on which PV panels are installed is a 7-storey building, in addition, a 7-storey residential building can be considered a high-rise building in this city. Therefore, in this research, two different building heights are considered, 9 meters (3-storey building) and 21 meters (7-storey building).

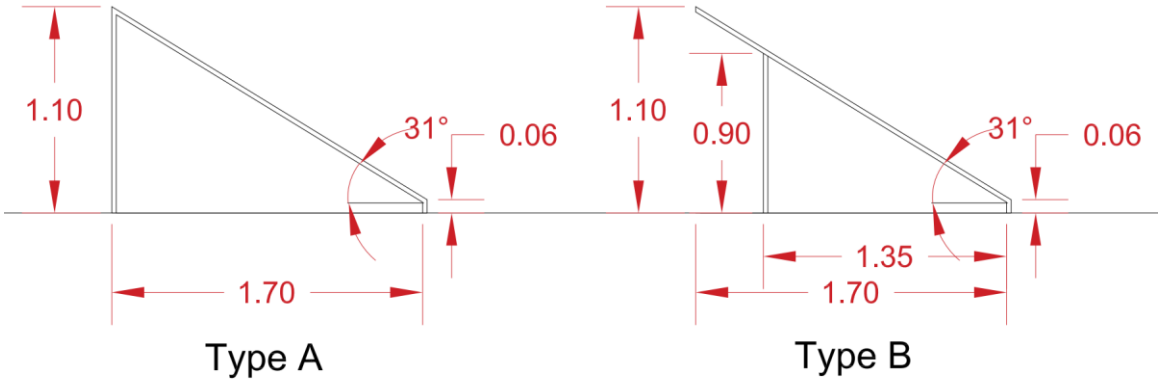
Span length. In general, the size of PV panels in the North Cyprus market, especially the panels used for roof installation, does not vary. In this study, the most common size of PV panel used in Northern Cyprus with dimensions of 992mm × 1956mm is chosen. The span length of the beams is one of the variables in this research. Different span lengths are considered in this study base on the size and number of panels, which are 1 meter, 1.5 meters, 2 meters, and 2.5 meters.

Load resisting systems. In this research, mounting systems are designed with two different types of load resisting systems, which are the bracing system and the moment frame system.

Arrangement of columns. The arrangement of the columns is one of the variables that has been considered to study its effect on the deflection of the beams. Two different arrangements of columns are considered, which are Type A and Type B. In Type A, the columns are located in the corners of the structure, and in type B, the columns are located at a distance from the corners. (Figure 15)

Figure 15

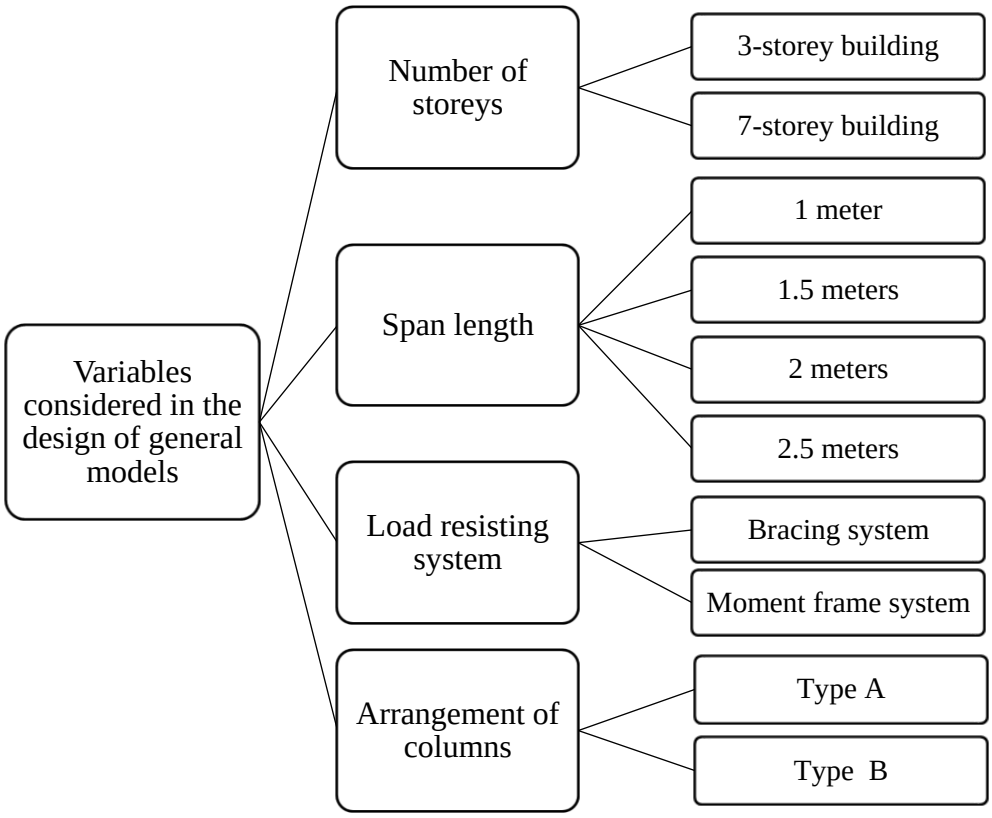
Section View of the Arrangement of Columns: Type A and Type B



The mentioned variables are summarized in (Figure 16).

Figure 16

Variables Considered in the Design of General Models



Models for Residential buildings

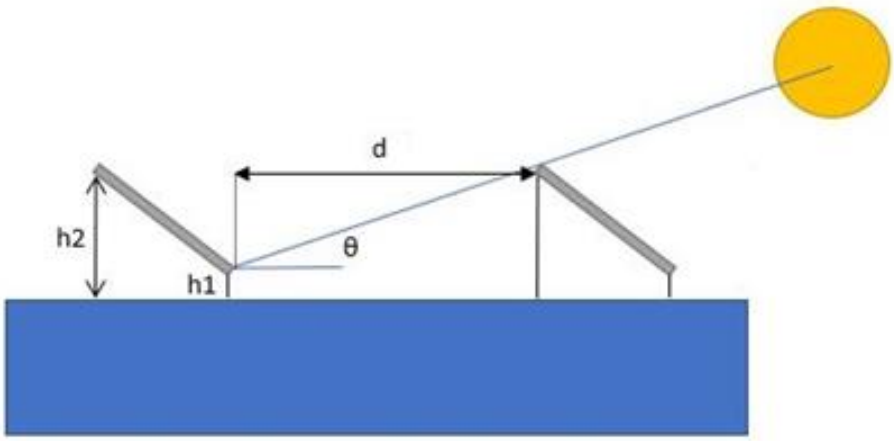
In addition to the mentioned models, two different types of flat-roofed residential buildings with the same available roof area but different orientations to the north have been considered and rooftop PV panel mounting systems are designed to

be installed on the roof of these buildings. The maximum number of panels that can be installed is determined for both types of buildings based on the available area on the roof of these buildings and the minimum allowable distance between the arrays. These PV panel mounting systems are designed considering variables including span length, the height of the building, and the type of load resisting system. Afterward, the optimal mounting system is determined based on the weight of the mounting system, the cost of the mounting system, and aesthetics.

The dimensions of the roof are 10 × 20 and according to the relevant standards, PV panels should be installed at a distance of at least 1 meter from the edge of the roof for aesthetic reasons and to facilitate access. PV panels in the Northern hemisphere should face south, and the proper slope angle for PV panels in this area (Nicosia, Northern Cyprus) is 31-32 degrees. In addition, an appropriate distance must be provided between the panel arrays to prevent the shadows of the panels on each other. The calculation for the minimum required distance between the arrays of PV panels in Nicosia is as follows:

Figure 17

The Distance Between the Arrays of PV Panels



$$d = \frac{h_2 - h_1}{tan\theta}$$

Where:

h_1= The shortest side of the installation system

h_2= The highest side of the installation system

θ = Solar elevation angle

d= The distance between two arrays

Given:

$$h_1 = 6\ cm,\ \ h_2 = 110\ cm,\ \ \theta = 55°$$

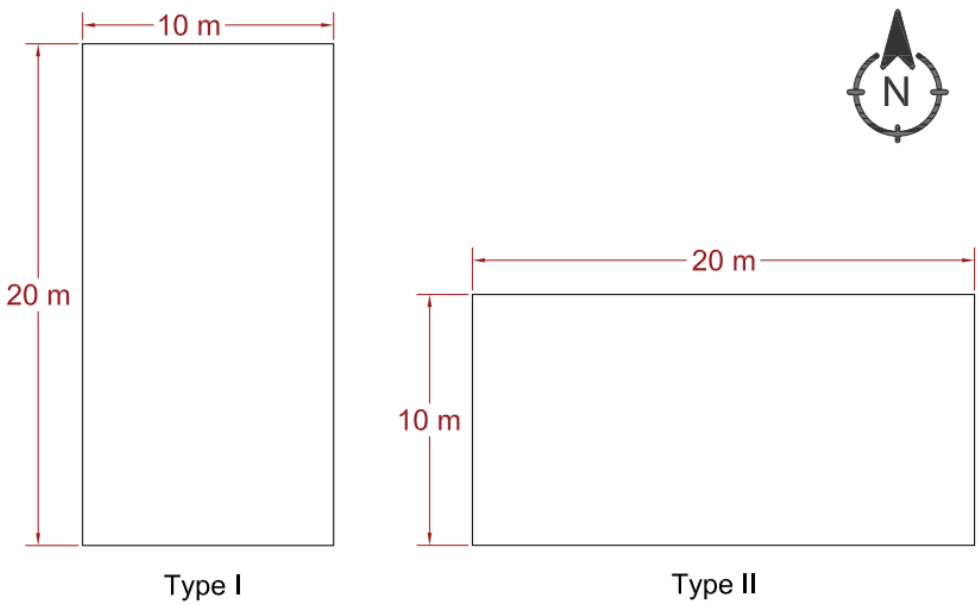
$$d = \frac{h_2 - h_1}{tan\theta} = \frac{104}{\tan 55°} \approx 73\ cm$$

The distance between the arrays is considered to be 1 meter.

As mentioned earlier, two different orientations to the north have been considered for the residential buildings. (Figure 18)

Figure 18

Plan View of the Orientation of Buildings to the North



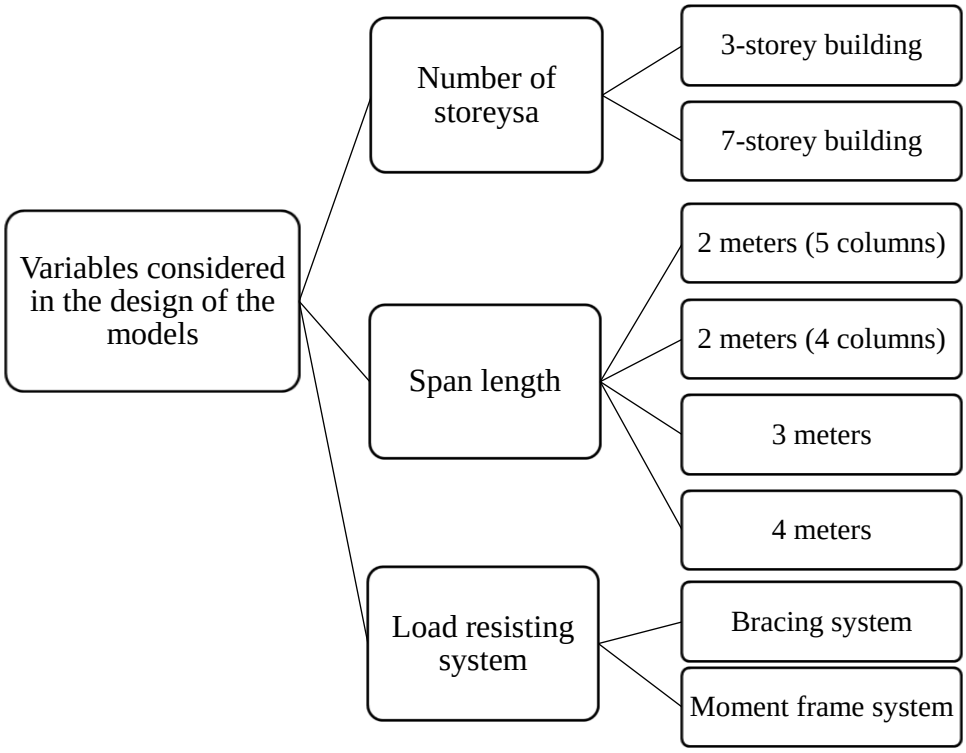
✓ **Type I**

Considering the mentioned conditions (available roof area, distance from the roof edge, tilt angle of PV panels, and distance between arrays), 56 PV panels (7 rows of 8 panels) can be installed on the roof of structure Type I.

The variables presented in (Figure 19) are considered to design the PV panel mounting systems for installation on the roof of this type of structure. As a result, 16 mounting systems are designed to support 56 panels on the roof of this type of building, and the mounting systems are compared in terms of the weight of the mounting system, cost, and aesthetics, and the optimum model is identified.

Figure 19

Variables Considered in the Design of Mounting systems for Type I Buildings



The span lengths and column arrangements for these models are shown in (Figure 20) and (Figure 21).

Figure 20

Span Lengths and Column Arrangements for (Type I), (A) 2 Meters (5 Columns), (B) 2 Meters (4 Columns), (C) 3 Meters, (D) 4 Meters (Moment Frame System)

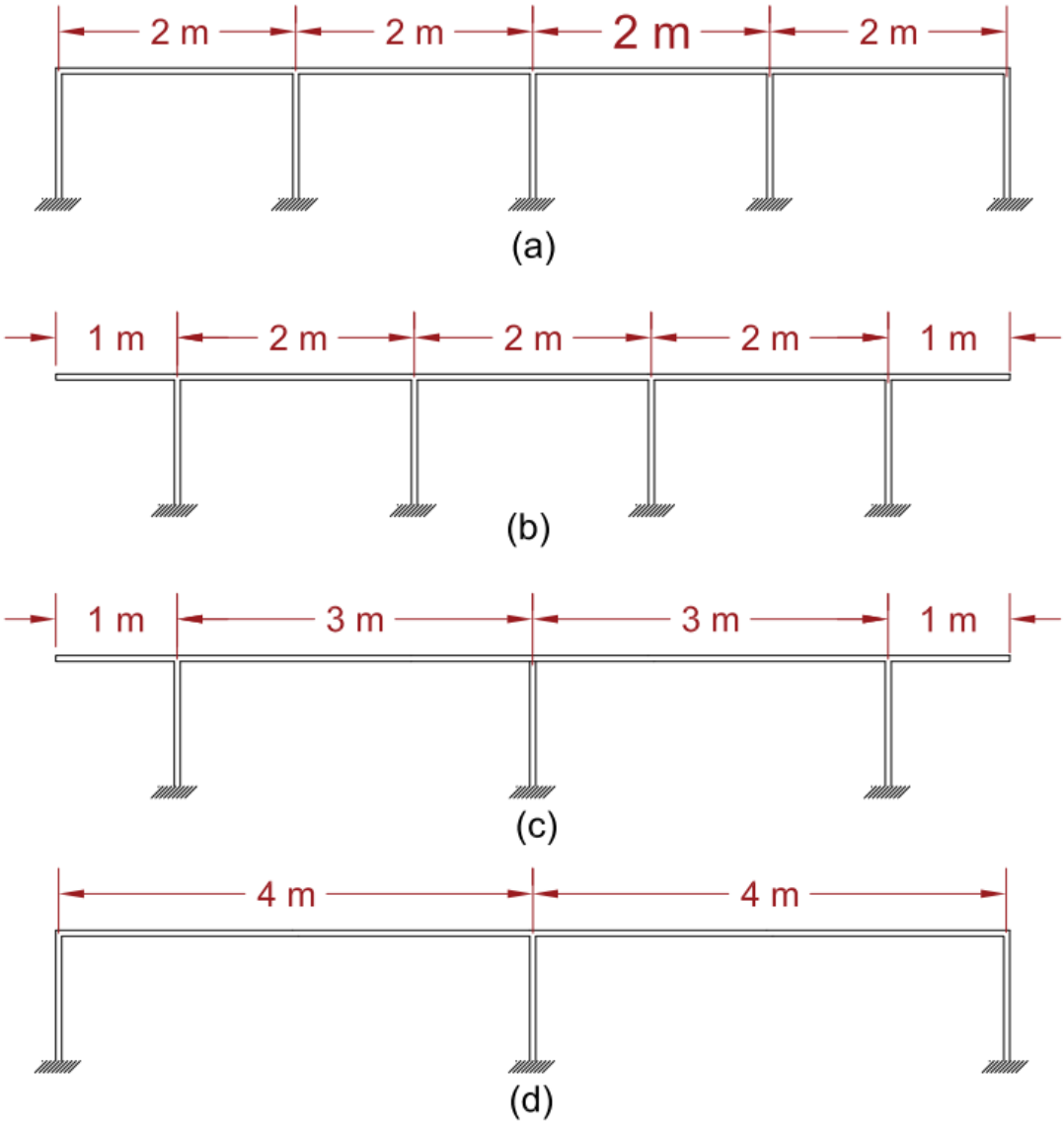
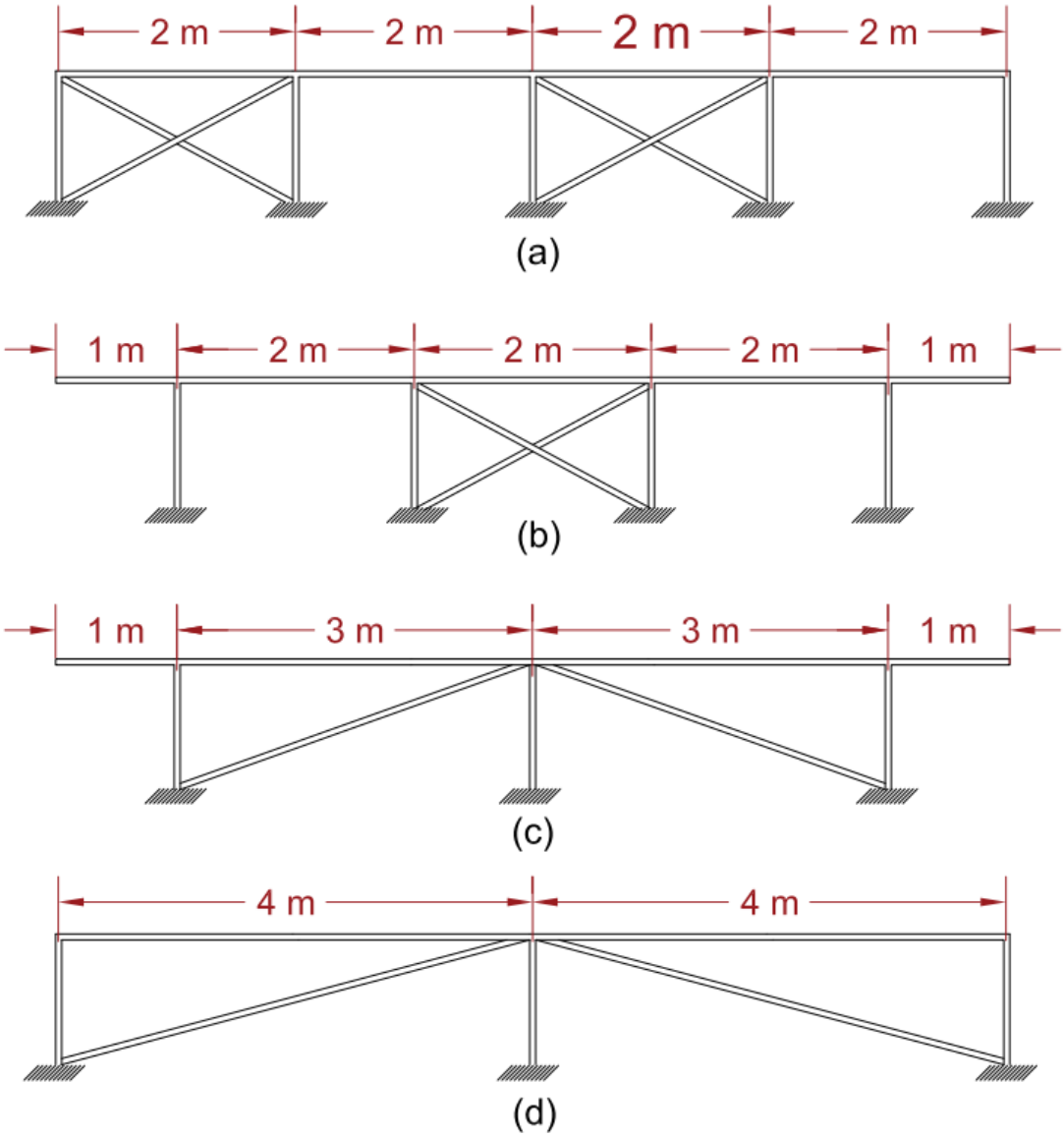


Figure 21

Span Lengths and Column Arrangements for (Type I), (A) 2 Meters (5 Columns), (B) 2 Meters (4 Columns), (C) 3 Meters, (D) 4 Meters (Bracing System)



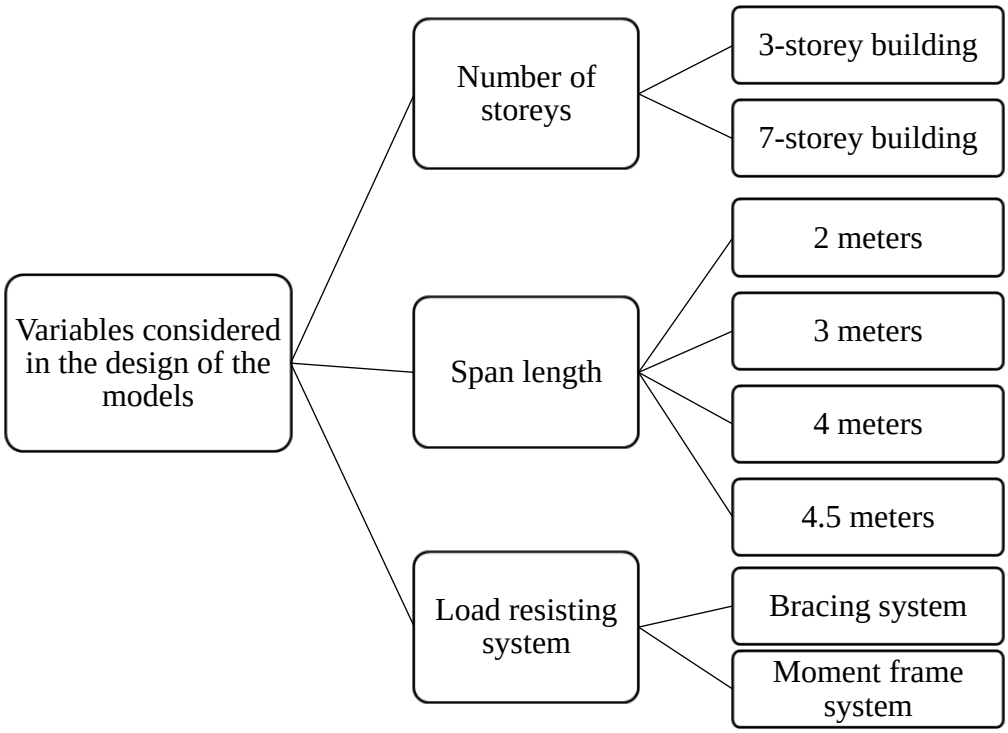
✓ **Type II**

Considering the mentioned conditions (available roof area, distance from the roof edge, tilt angle of PV panels, and distance between arrays), 54 PV panels (3 rows of 18 panels) can be installed on the roof of structure Type II.

The variables presented in (Figure 22) are considered to design the PV panel mounting systems for installation on the roof of this type of structure. As a result, 16 mounting systems are designed to support 54 panels on the roof of this type of building, and the mounting systems are compared in terms of the weight of the mounting system, cost, and aesthetics, and the optimum model is identified.

Figure 22

Variables Considered for the Design of Mounting systems for Type II Buildings



Different span lengths and the arrangement of the columns of these models are shown in (Figure 23) and (Figure 24).

Figure 23

Span Lengths and Column Arrangements for (Type II), (A) 2 Meters, (B) 3 Meters, (C) 4 Meters, (D) 4.5 Meters (Moment Frame System)

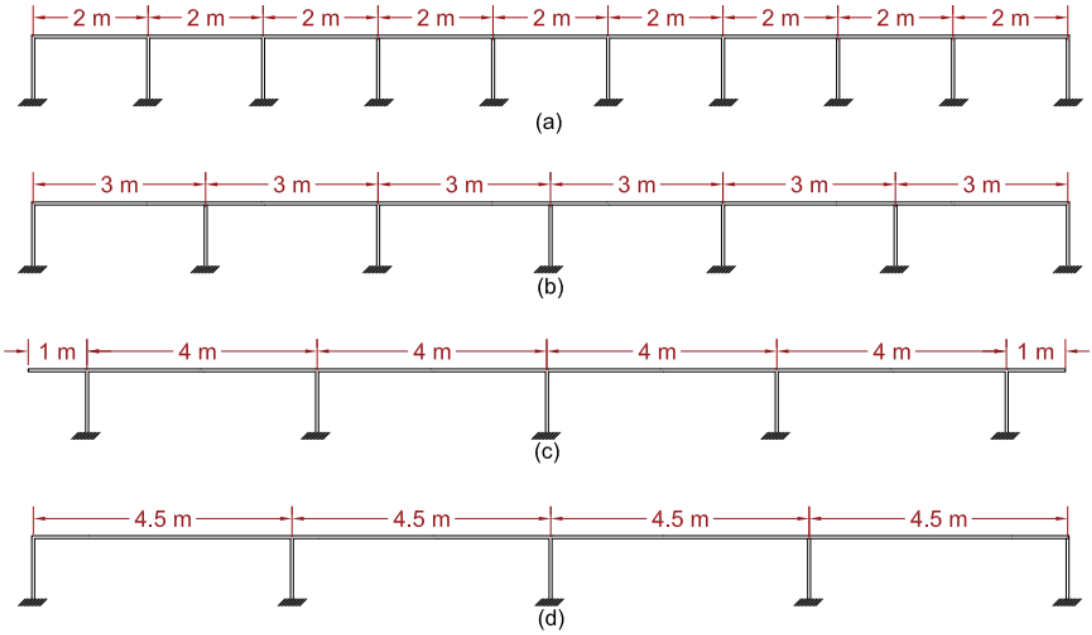
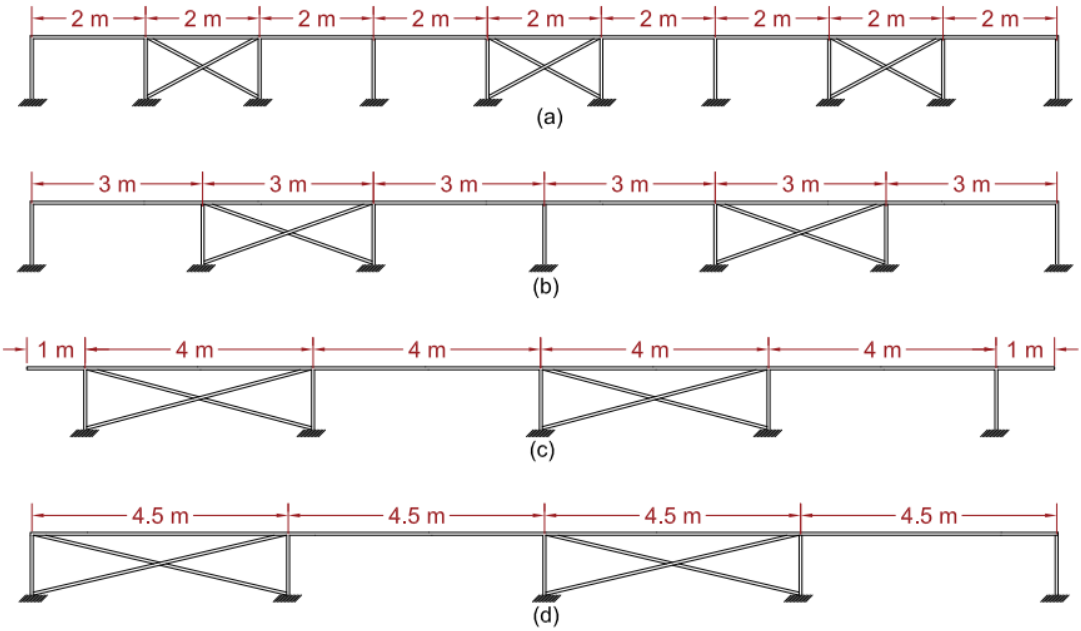


Figure 24

Span Lengths and Column Arrangements for (Type II), (A) 2 Meters, (B) 3 Meters, (C) 4 Meters, (D) 4.5 Meters (Bracing System)



Standards and Software

TS498 (Design Loads for Buildings, Turkish Standard) and ASCE Standard 7-16 (American Society of Civil Engineers: Minimum Design Loads for Buildings and Other Structures) are used for load calculations. AISC 360-16 standard is used for designing the steel mounting system. ETABS 2015 (Extended Three-Dimensional Analysis of Building Systems 2015) software program is utilized during this study to model, analyze and design the mounting systems.

Material Properties

According to the Northern Cyprus Solar Power Generation Plant Technical Specification, which in Turkish is called "Kuzey Kıbrıs Güneş Enerjisi Üretim Santrali Teknik Şartnamesi", PV panel mounting systems must be made of ST37, ST44, or ST52. Steel ST37 is a frequently used steel in industry and it is divided into ST37-2, USt37-2, RSt37-2, and ST37-3. ST37-2 is low-carbon steel with a carbon content of 0.20%, equivalent to S235JR or Q235. It is commonly used in structural applications where great strength is not required (Siagian et al., 2018). ST37-2 is selected for this study and its properties are listed in (Table 1).

Table 1

Properties of the Material

Parameter	Value
Weight per unit volume	7850 kgf/m^3
Modulus of elasticity, E	2×10^6 kgf/cm^2
Poisson's ratio, U	0.3
Shear modulus, G	769230.8 kgf/cm^2
Minimum yielding stress, F_y	2400 kgf/cm^2
Minimum tensile stress, F_u	3700 kgf/cm^2

(Figure 25) and (Figure 26) show how this material is defined in the software:

Figure 25

Material Definition in the Software

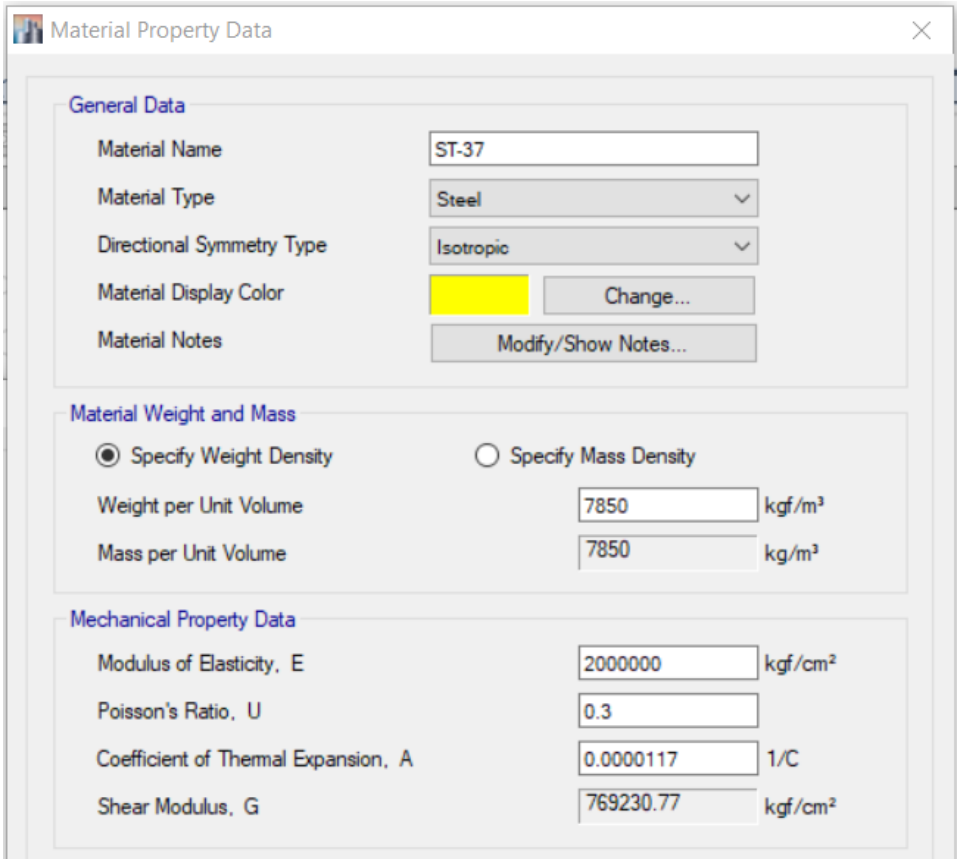
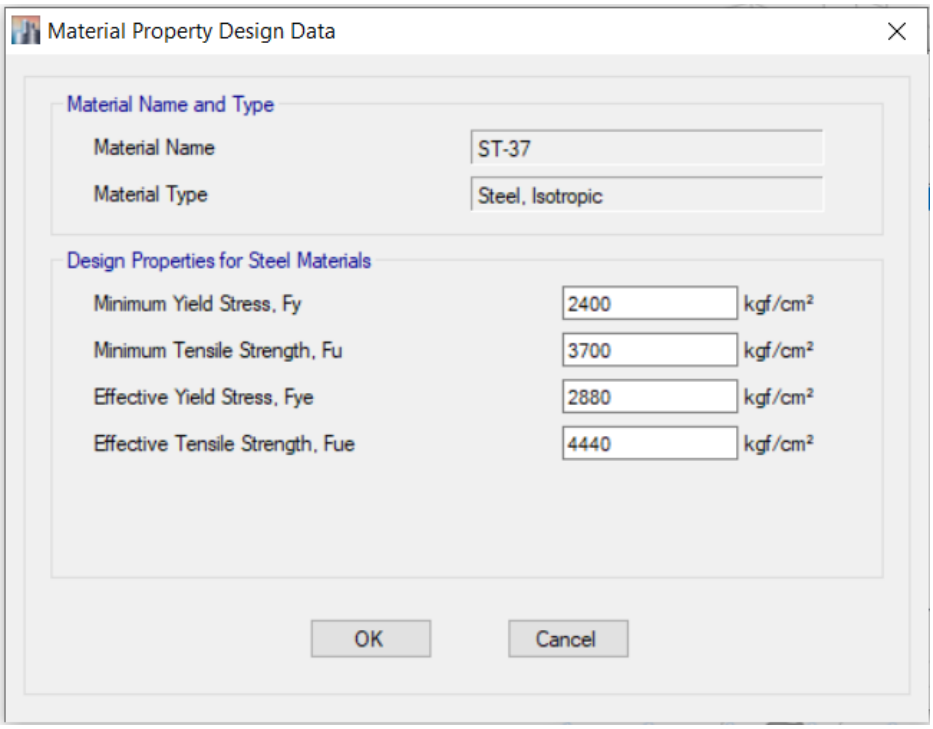


Figure 26

Material Definition in the Software



Load Calculations

Loading of a structure should be done in accordance with the conditions of the structure to ensure that the structure is efficient and does not fail during its service life. Each structure is subjected to different loads depending on the use of the building, construction site, structural features such as height and materials used, and climatic and environmental conditions. The loads that must be considered for the design of the PV panel mounting system in the study area are described below.

Dead load

The dead load in this study consists of two parts: the weight of the mounting system and the weight of PV panels and associated equipment. Based on the selected material and the dimensions of the structural elements, the weight of the mounting system is automatically calculated by ETABS software. Interviews and catalogs of PV panel manufacturers are used to determine the weight of PV panels and associated equipment.

Depending on the type of panel and the manufacturer, the weight of each PV panel may vary from 20 kg to 35 kg. The weight of each PV panel in this study is estimated at 35 kg, which is 17.5 kg/m considering the dimensions of the panels.

Wind load

In designing and constructing a PV panel mounting system, one of the most significant factors to consider is wind load. PV panel mounting systems, especially those installed on roofs, are exposed to strong winds and thus are vulnerable to failure. Wind loads can cause significant structural damage, including partial or total loss of the PV panel arrays, possible damage to adjacent facilities, human and financial losses, electricity shortages, power outages, and damage to other buildings (Naeiji, 2017). Therefore, trustworthy data and proper wind load assessment on PV panel mounting systems are essential for the safe, efficient, and economical design of mounting systems (Moravej,2015).

There are different standards for loads on buildings and structures, two of which are used to calculate the wind loads in this study; TS498 (Design Loads for Buildings, Turkish Standard) and ASCE 7-16 (American Society of Civil Engineers: Minimum Design Loads for Buildings and Other Structures). In the following, the procedures for calculating wind loads based on these two standards are explained.

Wind load calculations based on TS498. According to TS498, the wind load on various structures depends on two parameters, which are the structural type coefficient and the net wind pressure. Based on this standard, wind load is calculated using the following formula:

$$W = C_p q$$

Where:

W= Wind pressure ($\frac{kN}{m^2}$)

C_p =Structural type coefficient

q = Net wind pressure ($\frac{kN}{m^2}$)

Net wind pressure (q) is obtained using (Table 2) and considering the height of the structure from the ground.

Table 2

Wind Speed and Net Wind Pressure Based on the Height of The Structure (TS498)

Zeminden Yükseklik m	Rüzgar Hızı v m/s	Emme q (kN/m^2)
0 - 8	28	0,5
9 - 20	36	0,8
21 - 100	42	1,1
> 100	46	1,3

The structural type coefficient (C_p) depends on the tilt angle of the desired surface and the condition of the area where the building is located, which is obtained from (Figure 27), (Table 3), and (Table 4).

Figure 27

Structural Type Coefficient of Different Surfaces (TS498)

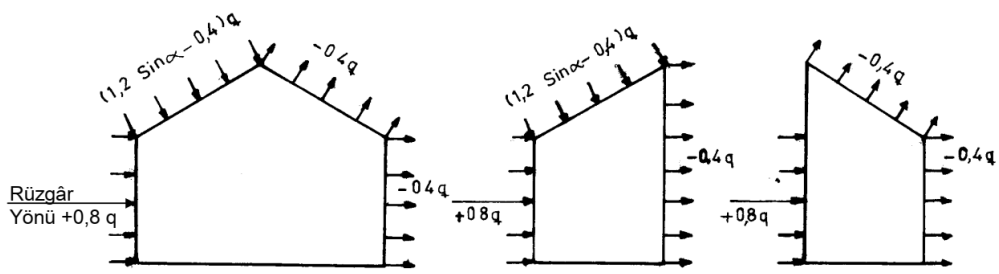


Table 3

C_p Coefficient and Distribution of Wind Load by Unit Area of the Affected Surface (TS498)

Yapı Cinsi	Katsayı C	Rüzgâr Yükü W = c.q			
		q = 0,5 kN/m^2	q = 0,8 kN/m^2	q = 1,10 kN/m^2	q = 1,30 kN/m^2
1) Düzlemsel yüzeyler ile sınırlandırılmış yapı elemanları (Madde 2 istisna)					
1.1)Kapalı Yapı Elemanları					
1.1.1)Rüzgar yönüne dikey yüzeylerde					
a)Genel olarak	1,2	0,60	0,96	1,32	1,56
b)Kule tipi yapı-larda(*)	1,6	0,80	1,28	1,76	2,08
1.1.2)Rüzgar yönüne α açısı yapan eğimli yüzeylerde					
a)Genel olarak	1,2 Sinα	0,60 Sinα	0,96 Sinα	1,32 Sinα	1,56 Sinα
b)Kule tipi yapılarda	1,6 Sinα	0,80 Sinα	1,26 Sinα	1,32 Sinα	1,56 Sinα
1.2)Kapalı Olmayan Yapı Elemanlarında (**) 1.1.1 ve 1.1.2 deki verilen değerler geçer-lidir. Yalnız gayri müsait durumu vermesi halinde bu yükler için ikinci bir hesap daha yapılmalıdır. Bu hesap-ta rüzgâr yükü çatı iç kısım yüzeyine dik olarak alınır.	1,2	0,60	0,96	1,32	1,56
1.3)Zemin üzerinde serbest duran duvarlar -Genel olarak yüksekliği, ortalama genişliğin 5 katı olan duvarlar	1,6	0,80	1,28	1,76	2,00
2)Taşıyıcı sistemler ve taşıyıcı dolu duvarlar					
2.1)Taşıyıcı bir duvar, ardarda sürekli olan taşıyıcı duvarlardan en öndeki ve diğer duvarların etkilenecek kısmı için					
a)Rüzgar yönüne dikey yüzeylerde	1,6	0,80	1,28	1,76	2,08
b)Rüzgar yönüne α açısı yapan eğimli yüzeylerde	1,6Sinα	0,80 Sinα	1,28 Sinα	1,76 Sinα	2,08 Sinα

Table 4

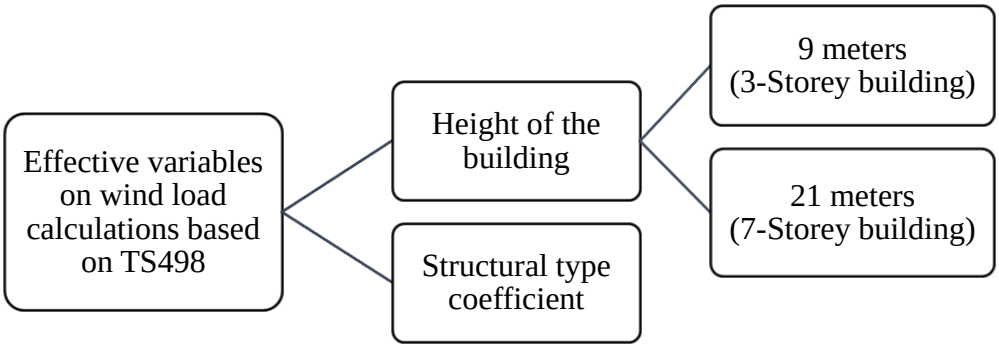
C_p Coefficient and Distribution of Wind Load by Unit Area of the Affected Surface (TS498) (Continued)

Yapı Cinsi	Katsayı C	Rüzgâryükü W = c.q			
		q = 0,5 kN/m^2	q = 0,8 kN/m^2	q = 1,10 kN/m^2	q = 1,30 kN/m^2
2.2)Ardarda olan taşıyıcı duvarlarda en öndeki duvar tarafından yüzeyi kapatılan ikinci taşıyıcı duvar ve diğerlerinin rüzgar yönünde rüzgara maruz kalmaları halinde					
a)taşıyıcı sistemlerdeki aralıkların sistem genişliğinden küçük olması ve taşıyıcı dolu duvarların taşıyıcı yüksekliğinden küçük olması halinde	0	0	0	0	0
b)Taşıyıcı aralıkları büyük ise					
I)Rüzgar yönüne dikey yüzeylerde	1,2	0,60	0,96	1,32	1,56
II)Rüzgar yönüne α açısı yapan eğimli	1,2 Sinα	0,60 Sinα	0,96 Sinα	1,32 Sinα	1,56 Sinα

In this study, the structural type coefficient is constant due to the fixed location and fixed tilt angle of the panels, but two different heights of the building are considered:

Figure 28

Effective Variables on Wind Load Calculations Based on TS498



Wind load calculations based on ASCE 7-16. According to ASCE 7-16, wind loads on rooftop PV panels depend on various variables including building risk category, basic wind speed in the area, type of structure, exposure category of the area, topographic condition of the area, ground elevation above sea level in desire area, the height of the building, height of the PV panel at the top and bottom edge of the arrays, height of parapet, panel size, length and width of the building, the title angle of PV

panels, shape, dimensions and arrangement of PV panel arrays, and distance between the mounting system and the edge of the roof.

According to this standard, the wind load on the rooftop PV panels mounting system is calculated as follows:

- Determination of the risk category of the building by using (Table 5).

Table 5

Risk Category of Buildings and Other Structures for Flood, Wind, Snow, Earthquake, and Ice Loads (ASCE 7-16)

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life	III
Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure	
Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released[a]	
Buildings and other structures designated as essential facilities	IV
Buildings and other structures, the failure of which could pose a substantial hazard to the community Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released[a]	
Buildings and other structures required to maintain the functionality of other Risk Category IV structures	

Besides, according to this standard: "Risk Category for rooftop structures and rooftop equipment is equal to the greater of the following:

1. Risk Category for the building on which the equipment or appurtenance is located

2. Risk Category for any facility to which the equipment or appurtenance provides a necessary service."

- Determination of the basic wind speed for the applicable risk category, which is depending on the local condition.
- Determination of wind load parameters, including wind directionality factor, exposure category, topographic factor, and ground elevation factor.
  - ✓ Wind directionality factor (K_d) is determined by using (Table 6) and considering the structure type:

Table 6

Wind Directionality Factor (ASCE 7-16)

Structure Type	Directionality Factor K_d
Buildings	
Main Wind Force Resisting System	0.85
Components and Cladding	0.85
Arched Roofs	0.85
Circular Domes	1.0[a]
Chimneys, Tanks, and Similar Structures	
Square	0.90
Hexagonal	0.95
Octagonal	1.0[a]
Round	1.0[a]
Solid Freestanding Walls, Roof Top Equipment, and Solid Freestanding and Attached Signs	0.85
Open Signs and Single-Plane Open Frames	0.85
Trussed Towers	
Triangular, square, or rectangular	0.85
All other cross sections	0.95

  - ✓ Exposure category (A, B, C, or D) is determined by considering the location of the building and surroundings based on section 26.7 of the standard.
  - ✓ Topographic factor (K_{zt}) is determined by considering the topographic condition of the building site and using section 26.8.2 of the standard.
  - ✓ Ground elevation factor (K_e) is determined by considering the ground elevation of the building site above sea level and using **(**Table 7).

Table 7

Ground Elevation Factor (ASCE 7-16)

Ground Elevation above Sea Level		Ground Elevation Factor
ft	m	K_e
<0	<0	See note 2
0	0	1.00
1,000	305	0.96
2,000	610	0.93
3,000	914	0.90
4,000	1,219	0.86
5,000	1,524	0.83
6,000	1,829	0.80
>6,000	>1,829	See note 2

- Determination of the velocity pressure exposure coefficient (K_z) according to the height of the building above ground level and exposure category using (Table 8).

Table 8

Velocity Pressure Exposure Coefficients (ASCE 7-16)

Height above Ground Level, z		Exposure		
ft	m	B	C	D
0–15	0–4.6	0.57 (0.70)[a]	0.85	1.03
20	6.1	0.62 (0.70)[a]	0.90	1.08
25	7.6	0.66 (0.70)[a]	0.94	1.12
30	9.1	0.70	0.98	1.16
40	12.2	0.76	1.04	1.22
50	15.2	0.81	1.09	1.27
60	18.0	0.85	1.13	1.31
70	21.3	0.89	1.17	1.34
80	24.4	0.93	1.21	1.38
90	27.4	0.96	1.24	1.40
100	30.5	0.99	1.26	1.43
120	36.6	1.04	1.31	1.48
140	42.7	1.09	1.36	1.52
160	48.8	1.13	1.39	1.55
180	54.9	1.17	1.43	1.58
200	61.0	1.20	1.46	1.61
250	76.2	1.28	1.53	1.68
300	91.4	1.35	1.59	1.73
350	106.7	1.41	1.64	1.78
400	121.9	1.47	1.69	1.82
450	137.2	1.52	1.73	1.86
500	152.4	1.56	1.77	1.89

- Determination of velocity pressure (q_z) using the following equation.

$$q_z = 0.613 K_z K_{zt} K_d K_e V^2$$

Where:

q_z= Velocity pressure ($\frac{N}{m^2}$)

K_z = Velocity pressure exposure coefficient

K_{zt}= Topographic factor

K_d= Wind directionality factor

K_e= Ground elevation factor

V = Basic wind speed (m/s)

- Determination of net pressure coefficient for rooftop PV panels (GC_{rn}) using the following procedure:
  - ✓ Determination of parapet height factor (γ_p)

$$\gamma_p = \min\left(1.2, 0.9 + \frac{h_{pt}}{h}\right)$$

Where:

h= Mean roof height of a building (m)

h_{pt}= Mean parapet height above the adjacent roof surface (m)

  - ✓ Determination of panel chord factor (γ_c)

$$\gamma_c = \max(0.6 + 0.06 L_p, 0.8)$$

Where:

L_p= Panel chord length for use with rooftop PV panels

  - ✓ Determination of array edge factor (γ_E) which is 1.5 for uplift wind loads and 1.00 for downward wind loads.
  - ✓ Determination of nominal net pressure coefficient $(GC_{rn})_{nom}$ for rooftop PV panels using the following equations and (Figure 29).

$$L_b = \min(0.4(hW_L)^{0.5}, h, W_s)$$

$$A_n = \frac{1000}{\left(max\ (L_b, 4.57)\right)^2} \times A$$

Where:

L_b= Normalized building length (m)

h= Mean roof height of a building (m)

W_L= Width of a building on its longest side (m)

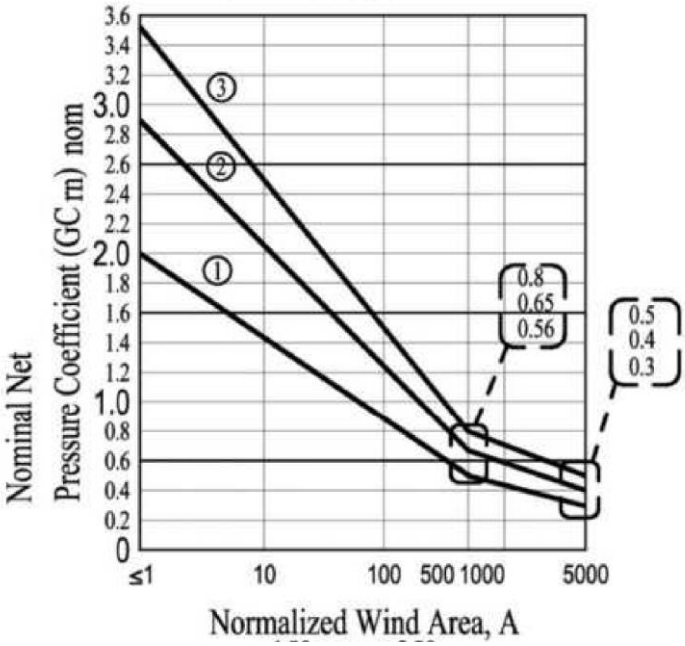
W_s= Width of a building on its shortest side (m)

A_n= Normalized wind area for rooftop PV panels

A= Effective wind area (m^2)

Figure 29

Nominal Net Pressure Coefficient for Rooftop PV Panels (ASCE 7-16)



✓ Determination of net pressure coefficient for rooftop PV panels (GC_{rn}) using the following formula:

$$(GC_{rn}) = \gamma_p \gamma_c \gamma_E (GC_{rn})_{nom}$$

Where:

γ_p = Parapet height factor for use with rooftop PV panels

γ_c = Panel chord factor for use with rooftop PV panels

γ_E = Array edge factor for use with rooftop PV panels

$(GC_{rn})_{nom}$= Nominal net pressure coefficient for rooftop PV panels

(GC_{rn})= Net pressure coefficient for rooftop PV panels

- Determination of design wind pressure for rooftop PV panels by using the following equation.

$$p = q_z(GC_{rn})$$

Where:

p = Design pressure to be used in the determination of wind loads for buildings ($\frac{N}{m^2}$)

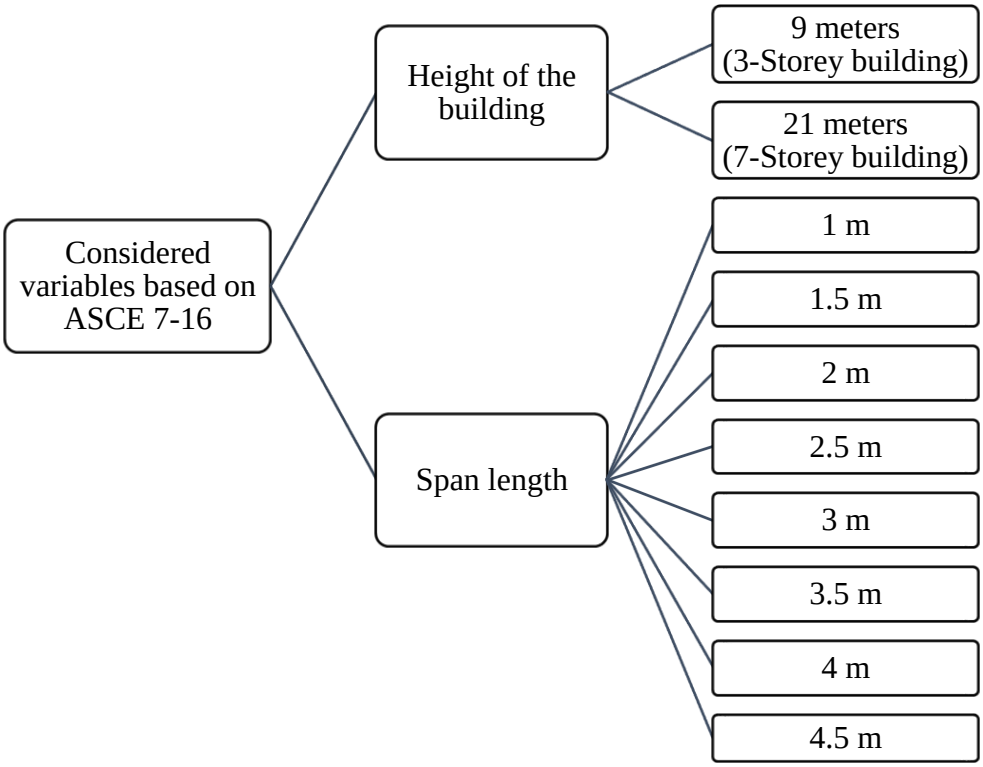
q_z= Velocity pressure ($\frac{N}{m^2}$)

(GC_{rn})= Net pressure coefficient for rooftop PV panels

According to this standard, wind load depends on various parameters, but in this study, two different variables including building height and span length are considered and wind calculations are performed by considering the variables as mentioned in (Figure 30).

Figure 30

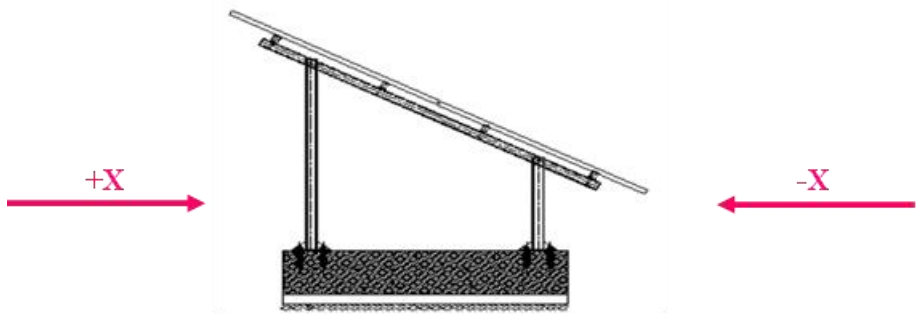
Variables Considered in Wind Load Calculations Based on ASCE 7-16



It should be noted that wind loads have been calculated using these two standards by considering two different wind directions, which are shown in (Figure 31).

Figure 31

Wind Load Directions



Wind blowing in the + X direction creates lifting loads on PV panels, hence it is known as uplift wind load. On the other hand, the wind blowing in the -X direction creates downward loads on PV panels, hence it is known as downward wind load. Uplift wind load and downward wind load on PV panels are shown in (Figure 32).

Figure 32

Uplift Wind Load on PV Panels

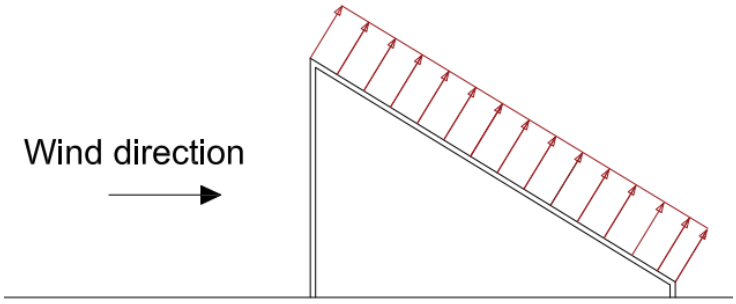
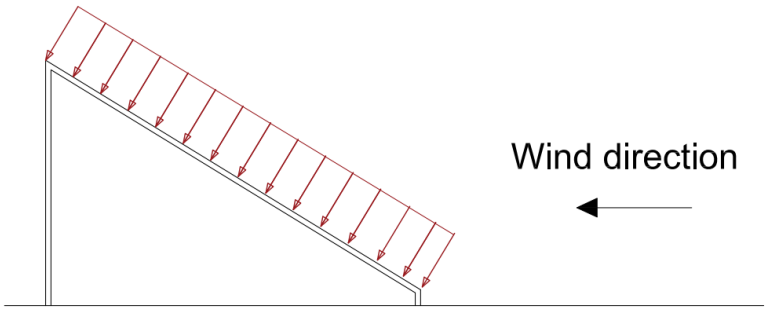


Figure 33

Downward wind load on PV panels



Wind load calculations based on TS498 and ASCE 7-16 are provided in Appendix A.

Seismic load

Seismic loads on mounting systems of rooftop PV panels are specifically provided by ASCE 7-16, and this standard has been used to calculate the earthquake loads in this study. According to this standard, the seismic load on mounting systems of rooftop PV panels depends on parameters such as spectral response acceleration parameter, short-period site coefficient at 0.2-s period, amplification factor, the importance factor of the structure, response modification, operating weight of the mounting system, the height of the building, and the height of the mounting system. Seismic loads are calculated using the following method provided by ASCE 7-16 and applied in both orthogonal directions at the center of the semi-rigid diaphragm with an eccentricity of 0.05%.

Seismic loads for rooftop PV panel mounting systems are calculated white the following formula:

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\frac{R_p}{I_p}} (1 + 2\frac{z}{h})$$

Where:

F_p = The seismic force acting on a component of a structure

S_{DS} = Spectral response acceleration parameter at a period of 1 s

a_p= The amplification factor related to the response of a system or component as affected by the type of seismic attachment

I_p= The component importance factor

W_p = Component operating weight (N)

R_p = Component response modification factor

z = Height in the structure of the point of attachment of component with respect to the base

h = Average roof height of the structure with respect to the base.

- Amplification factor (a_p) and response modification factor (R_p) are determined using (Table 9).

Table 9

Amplification Factor and Response Modification Factor Based on The Structural Type. (ASCE 7-16)

Architectural Component	a_p[a]	R_p
Interior nonstructural walls and partitions[c]		
Plain (unreinforced) masonry walls	1	1½
All other walls and partitions	1	2½
Cantilever elements (unbraced or braced to structural frame below its center of mass)		
Parapets and cantilever interior nonstructural walls	2½	2½
Chimneys where laterally braced or supported by the structural frame	2½	2½
Cantilever elements (braced to structural frame above its center of mass)		
Parapets	1	2½
Chimneys	1	2½
Exterior nonstructural walls[c]	1[b]	2½
Exterior nonstructural wall elements and connections[b]		
Wall element	1	2½
Body of wall panel connections	1	2½
Fasteners of the connecting system	1¼	1
Veneer		
Limited deformability elements and attachments	1	2½
Low-deformability elements and attachments	1	1½
Penthouses (except where framed by an extension of the building frame)	2½	3½
Ceilings		
All	1	2½
Cabinets		
Permanent floor-supported storage cabinets more than 6 ft (1,829 mm) tall, including contents	1	2½
Permanent floor-supported library shelving, book stacks, and bookshelves more than 6 ft (1,829 mm) tall, including contents	1	2½
Laboratory equipment	1	2½
Access floors		
Special access floors (designed in accordance with Section 13.5.7.2)	1	2½
All other	1	1½
Appendages and ornamentations	2½	2½
Signs and Billboards	2½	3
Other rigid components		
High-deformability elements and attachments	1	3½
Limited-deformability elements and attachments	1	2½
Low-deformability materials and attachments	1	1½
Other flexible components		
High-deformability elements and attachments	2½	3½
Limited-deformability elements and attachments	2½	2½
Low-deformability materials and attachments	2½	1½
Egress stairways not part of the building seismic force-resisting system	1	2½
Egress stairs and ramp fasteners and attachments	2½	2½

- Calculation of spectral response acceleration parameter at short periods (S_{DS}) by the following formula:

$$S_{DS} = \frac{2}{3} S_{MS}$$

S_{MS} is the risk-targeted maximum considered earthquake spectral response acceleration parameter at short periods adjusted for site class effects and it is calculated using the following formula:

$$S_{MS} = F_a S_s$$

S_s is the mapped risk-targeted maximum considered earthquake spectral response acceleration parameter at short periods and F_a is short-period site coefficient at 0.2-s period and it is calculated using (Table 10).

Table 10

Short-Period Site Coefficient At 0.2-S Period (ASCE 7-16)

	Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at Short Period					
Site Class	$S_S \leq 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S = 1.25$	$S_S \geq 1.5$
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.9	0.9	0.9	0.9	0.9	0.9
C	1.3	1.3	1.2	1.2	1.2	1.2
D	1.6	1.4	1.2	1.1	1.0	1.0

- The importance Factor is considered using the following section of the standard:

All components shall be assigned a component Importance Factor as indicated in this section. The component Importance Factor, I_p, shall be taken as 1.5 if any of the following conditions apply:

1. The component is required to function for life-safety purposes after an earthquake, including fire protection sprinkler systems and egress stairways.

2. The component conveys, supports, or otherwise contains toxic, highly toxic, or explosive substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released.

3. The component is in or attached to a Risk Category IV structure, and it is needed for the continued operation of the facility or its failure could impair the continued operation of the facility.

4. The component conveys, supports, or otherwise contains hazardous substances and is attached to a structure or portion thereof classified by the Authority Having Jurisdiction as a hazardous occupancy.

All other components shall be assigned I_p equal to 1.0.

Finally, F_p is not required to be taken as greater or less than:

$$F_p = 1.6\, S_{DS} I_p W_p$$

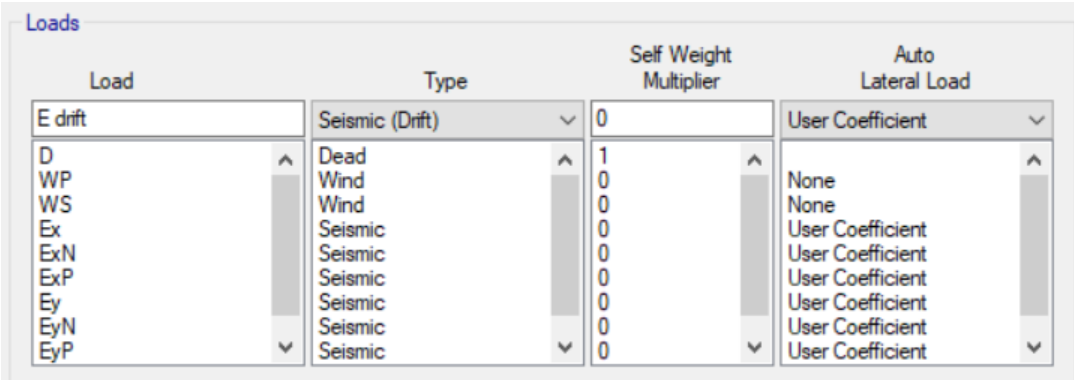
$$F_p = 0.3\, S_{DS} I_p W_p$$

Seismic load calculations based on ASCE 7-16 are provided in Appendix B.

The mentioned loads including the dead load, wind loads, and seismic loads are defined in the software as shown in (Figure 34).

Figure 34

Load Patterns Definition in The Software



Load Combinations

The load combinations used in the design of the mounting systems of PV panels are developed in accordance with ASCE 7-16 and are listed in (Table 11), where:

D: Dead load, W_d: Downward wind load, W_u: Uplift wind load, E_x: Earthquake load in the X direction, E_y: Earthquake load in the Y direction, E_x N: Earthquake load in the X direction with negative eccentricity, E_x P: Earthquake load in the X direction with positive eccentricity, E_y N: Earthquake load in the Y direction with negative eccentricity, E_y P: Earthquake load in the Y direction with positive eccentricity

Table 11

Design Load Combinations

Number	Combination Type	Load Combination
1	Gravity and wind loads combinations	$1.4D$
2		$1.2D + W_d$
3		$1.2D + W_u$
4		$0.9D + W_d$
5		$0.9D + W_u$
6	Earthquake loads combinations	$1.2D + E_x\ N + 0.3\ E_y$
7		$1.2D + E_x\ N - 0.3\ E_y$
8		$1.2D - E_x\ N + 0.3\ E_y$
9		$1.2D - E_x\ N - 0.3\ E_y$
10		$1.2D + E_x\ P + 0.3\ E_y$
11		$1.2D + E_x\ P - 0.3\ E_y$
12		$1.2D - E_x\ P + 0.3E_y$
13		$1.2D - E_x\ P - 0.3\ E_y$
14		$1.2D + 0.3E_x + E_y\ N$
15		$1.2D + 0.3E_x - E_y\ N$
16		$1.2D - 0.3E_x + E_y\ N$
17		$1.2D - 0.3E_x - E_y\ N$
18		$1.2D + 0.3E_x + E_y\ P$
19		$1.2D + 0.3E_x - E_y\ P$
20		$1.2D - 0.3E_x + E_y\ P$
21		$1.2D - 0.3E_x - E_y\ P$
22		$0.9D + E_x\ N + 0.3\ E_y$
23		$0.9D + E_x\ N - 0.3\ E_y$
24		$0.9D - E_x\ N + 0.3\ E_y$
25		$0.9D - E_x\ N - 0.3\ E_y$
26		$0.9D + E_x\ P + 0.3\ E_y$
27		$0.9D + E_x\ P - 0.3\ E_y$
28		$0.9D - E_x\ P + 0.3E_y$
29		$0.9D - E_x\ P - 0.3\ E_y$
30		$0.9D + 0.3E_x + E_y\ N$
31		$0.9D + 0.3E_x - E_y\ N$
32		$0.9D - 0.3E_x + E_y\ N$
33		$0.9D - 0.3E_x - E_y\ N$
34		$0.9D + 0.3E_x + E_y\ P$
35		$0.9D + 0.3E_x - E_y\ P$
36		$0.9D - 0.3E_x + E_y\ P$
37		$0.9D - 0.3E_x - E_y\ P$

Case Study

The case study of this research is a PV panel mounting system installed on a 3-storey residential building in Nicosia, Northern Cyprus. The roof of this building is flat and in early 2020, 16 PV panels with dimensions of 992 mm×1956 mm are installed on the roof of this building. This mounting system of PV panels has failed twice due to strong winds. The first time, the mounting system had difficulty carrying loads on a windy day, and some of the panels fell and broke, and the second time some panels are damaged on a windy day due to misconnections. As a result of this background, this mounting system has been considered as the case study in this investigation.

Figure 35

The Case Study Mounting System of PV Panels

The structure is inspected twice, the dimensions of the structural elements are measured, and some questions are asked of the residents. Then the mounting system is modelled using ETABS 2015, its status is checked, and structural problems are detected based on the results of the analysis and inspections. Finally, alternatives for the mounting system are presented in accordance with the building conditions, related standards, and available roof area.

Modelling the structure with ETABS 2015

As previously mentioned, ETABS 2015 is used to model the mounting system. The modelled structure is analyzed, its current status is investigated, and design problems are identified.

Based on the inspections and measurements performed, the steel frame section used for all elements of this mounting system is “SHS 5X5-0.26”, which is defined in the software as shown in (Figure 36) and (Figure 37).

Figure 36

Definition of the Steel Frame Section in The Software

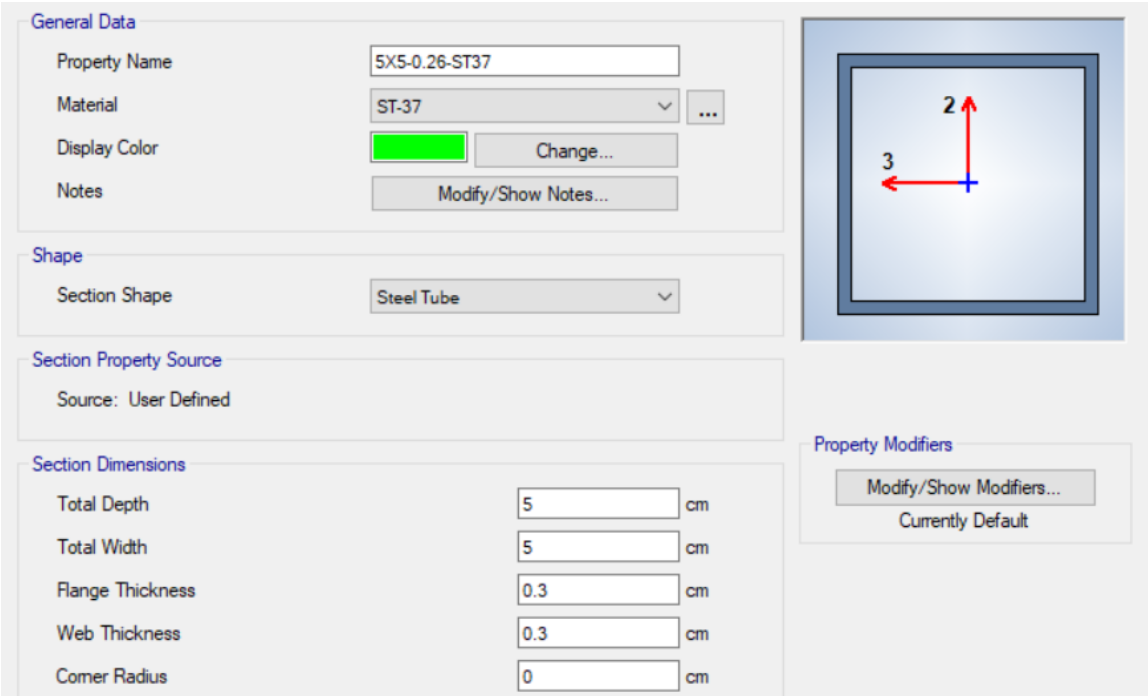


Figure 37

Used Frame Section Properties

Item	Value
Area, mm2	493
AS2, mm2	253.8
AS3, mm2	253.8
I33, mm4	185149.2
I22, mm4	185149.2
S33Pos, mm3	7406
S33Neg, mm3	7406
S22Pos, mm3	7406
S22Neg, mm3	7406
R33, cm	1.9
R22, cm	1.9
Z33, mm3	8771.2
Z22, mm3	8771.2
J, mm4	276890.7

Next figures show the plan view, elevation views, and a 3D model of the installation system.

Figure 38

Plan View of the Roof

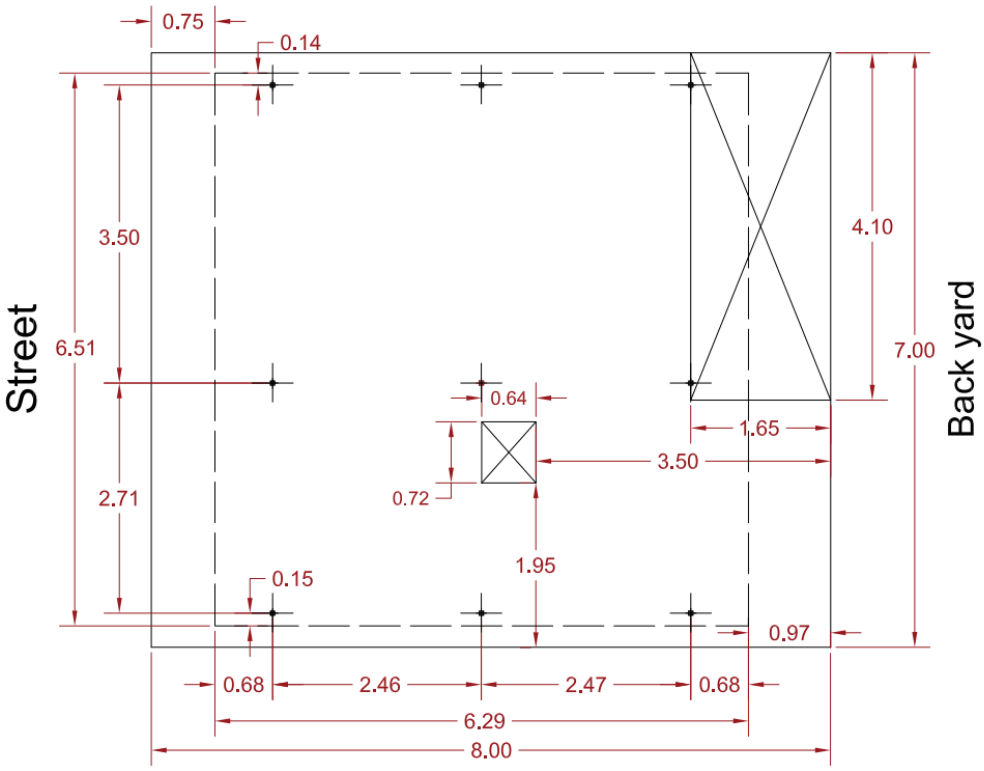


Figure 39

A 3D View of The Mounting System

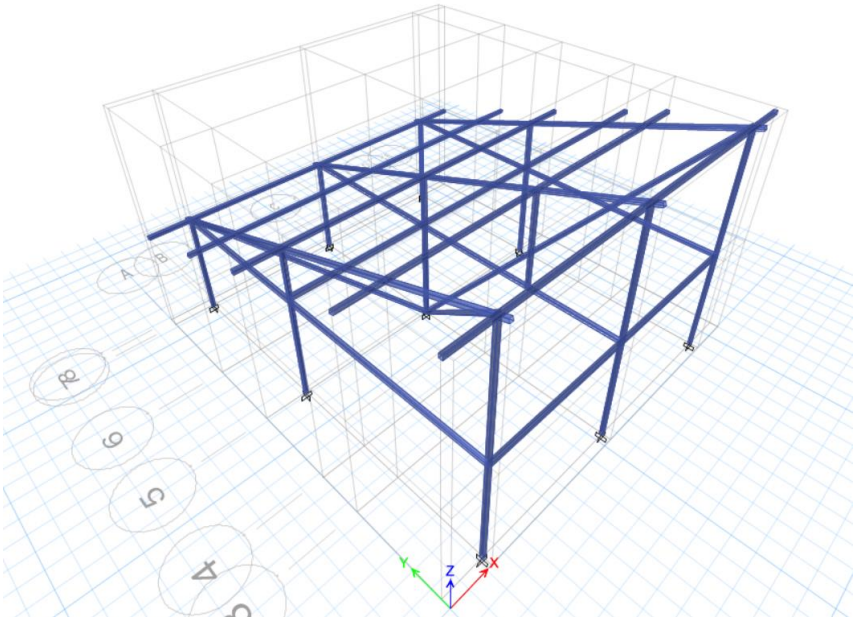


Figure 40

Plan View of the Structure

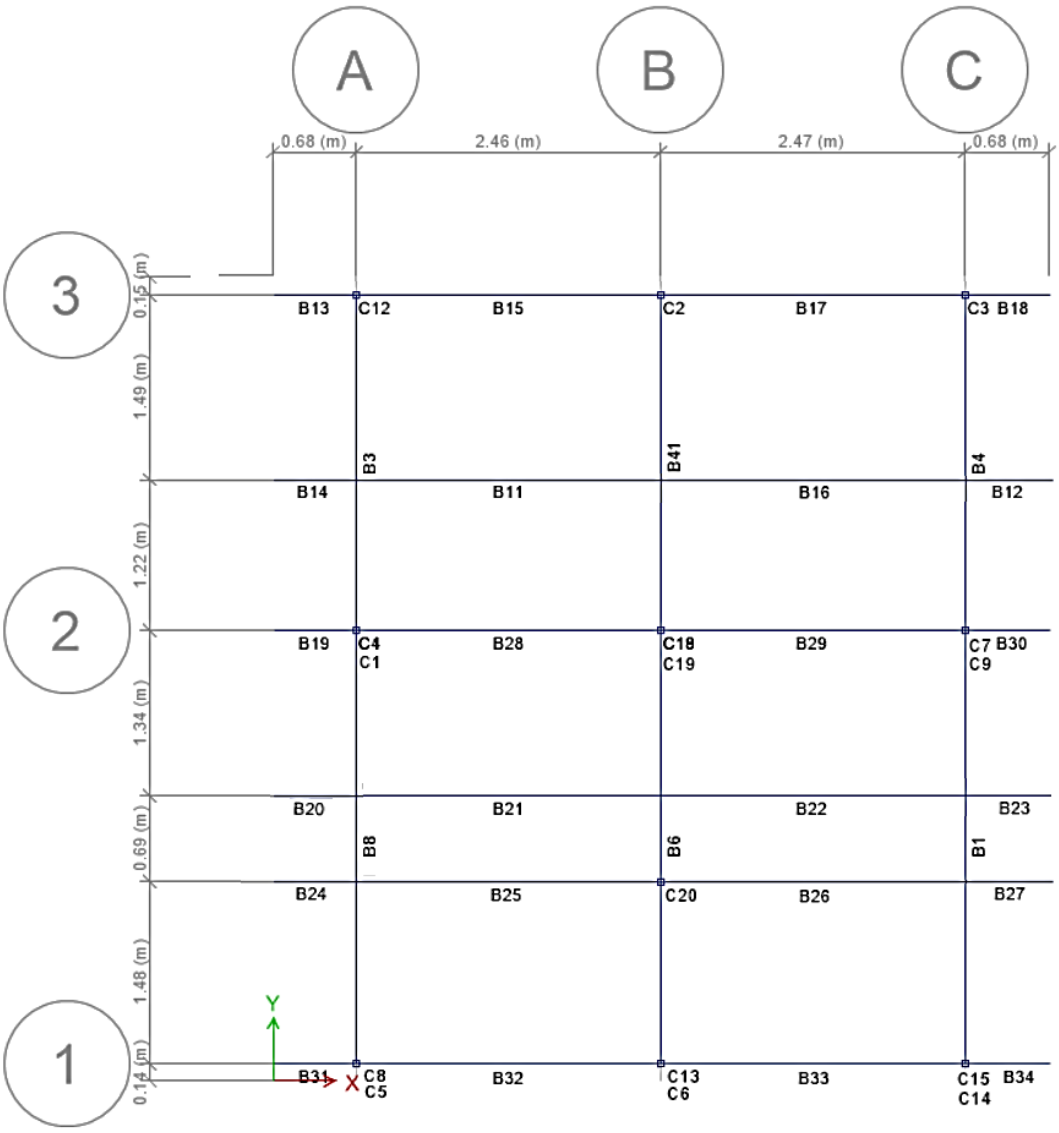


Figure 41

Elevation A of the Structure

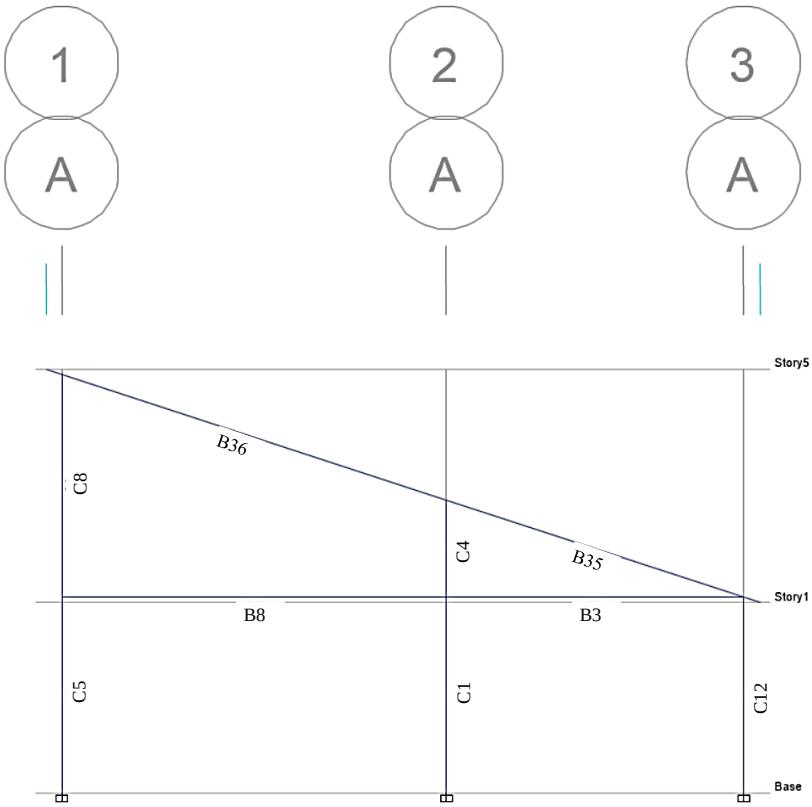


Figure 42

Elevation B of the Structure

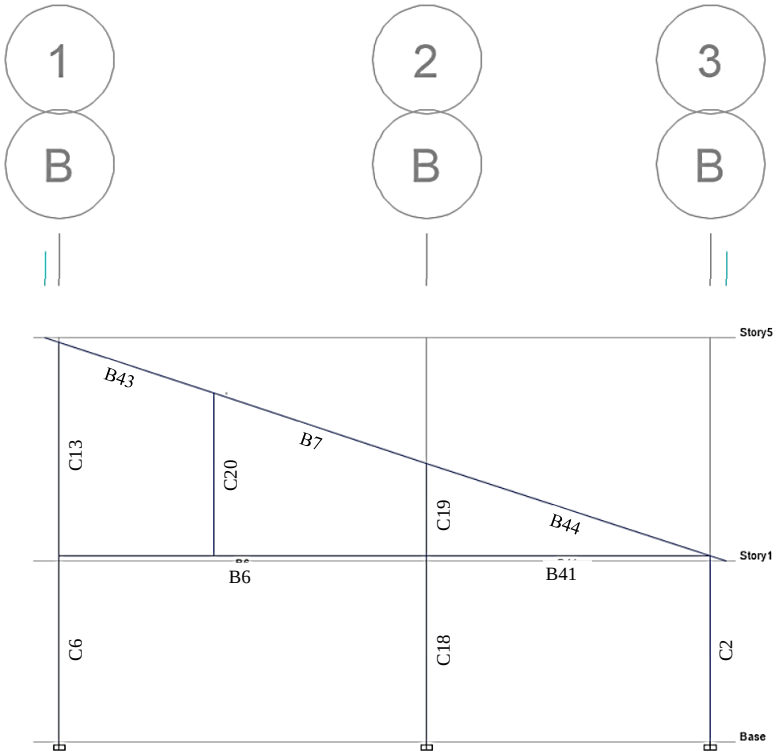


Figure 43

Elevation C of the Structure

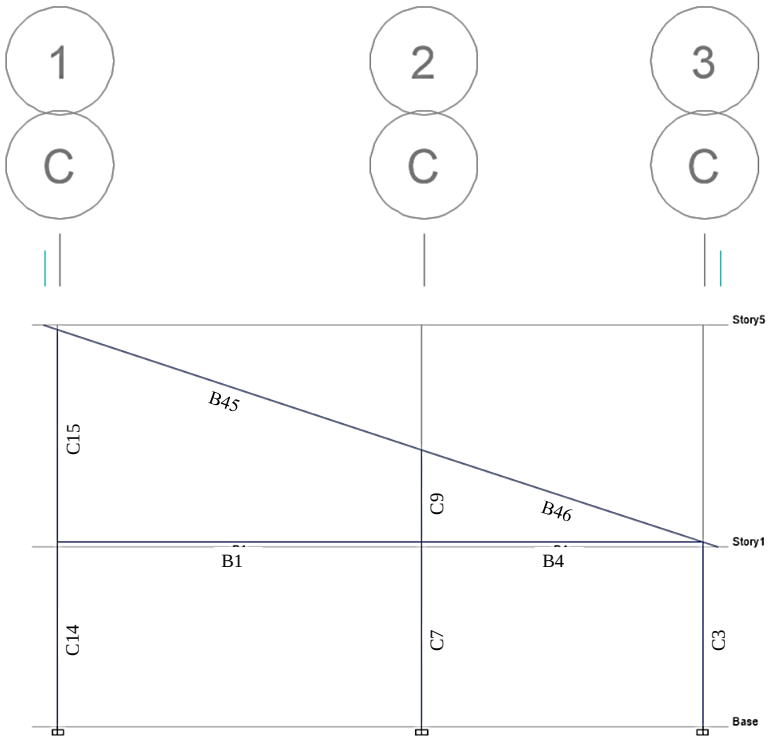


Figure 44

Elevation 1 of the Structure

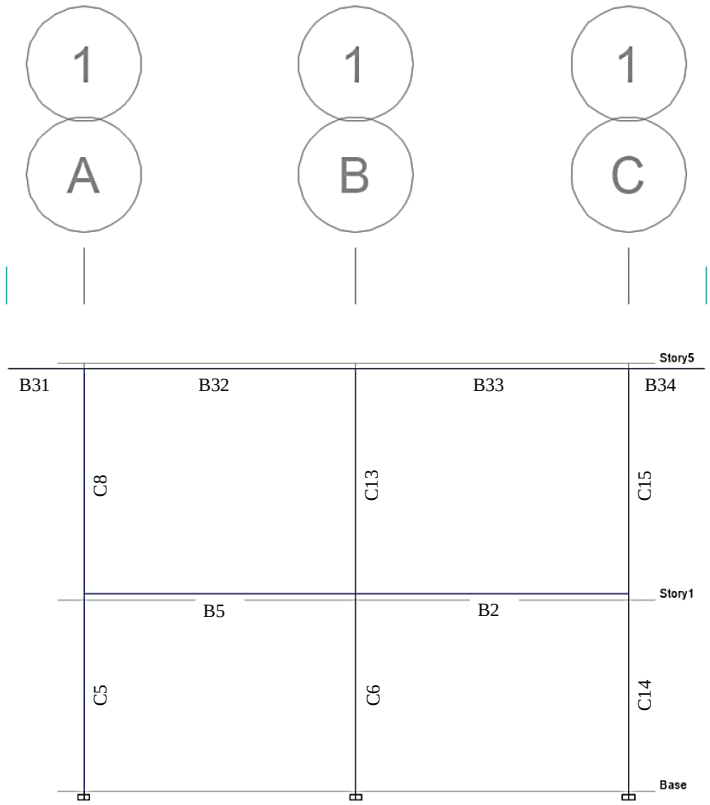


Figure 45

Elevation 2 of the Structure

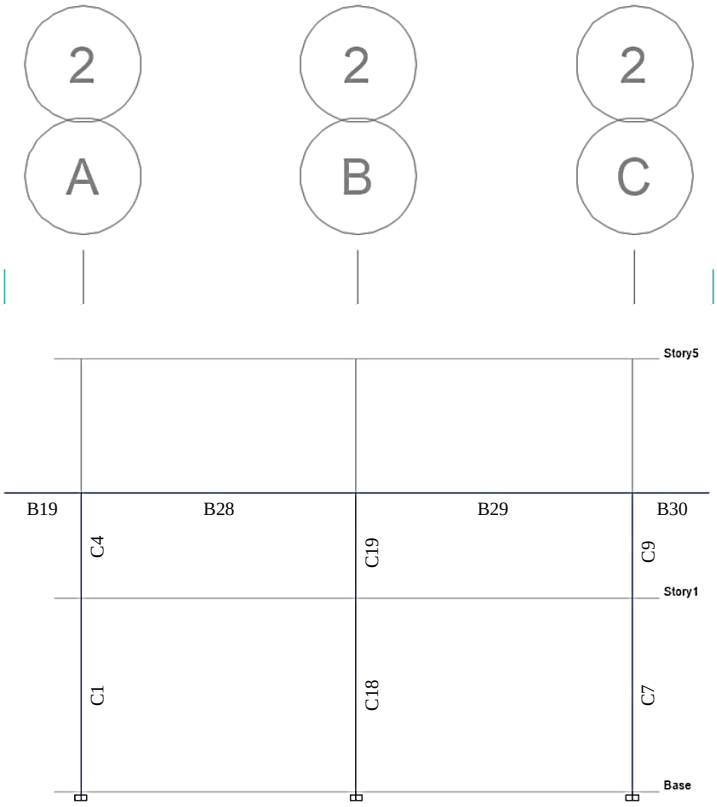
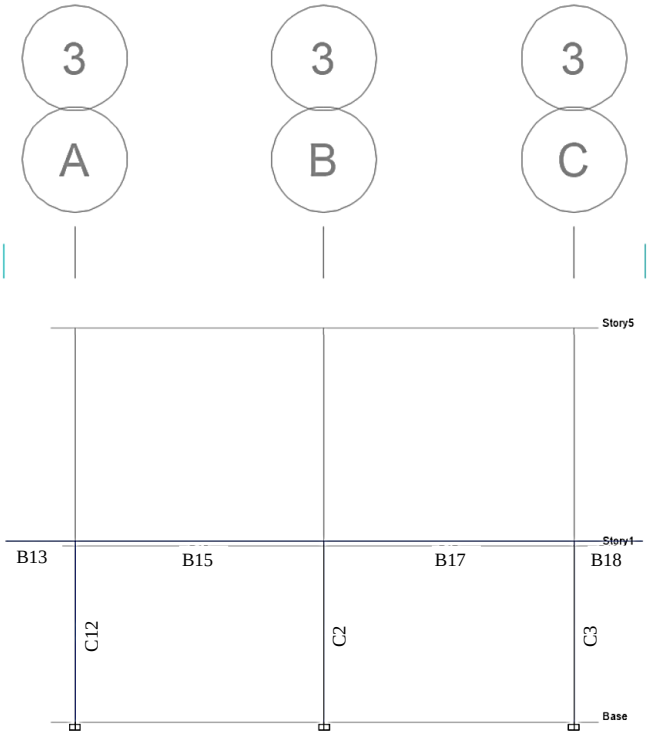


Figure 46

Elevation 3 of the Structure



The alternative mounting systems for the case study

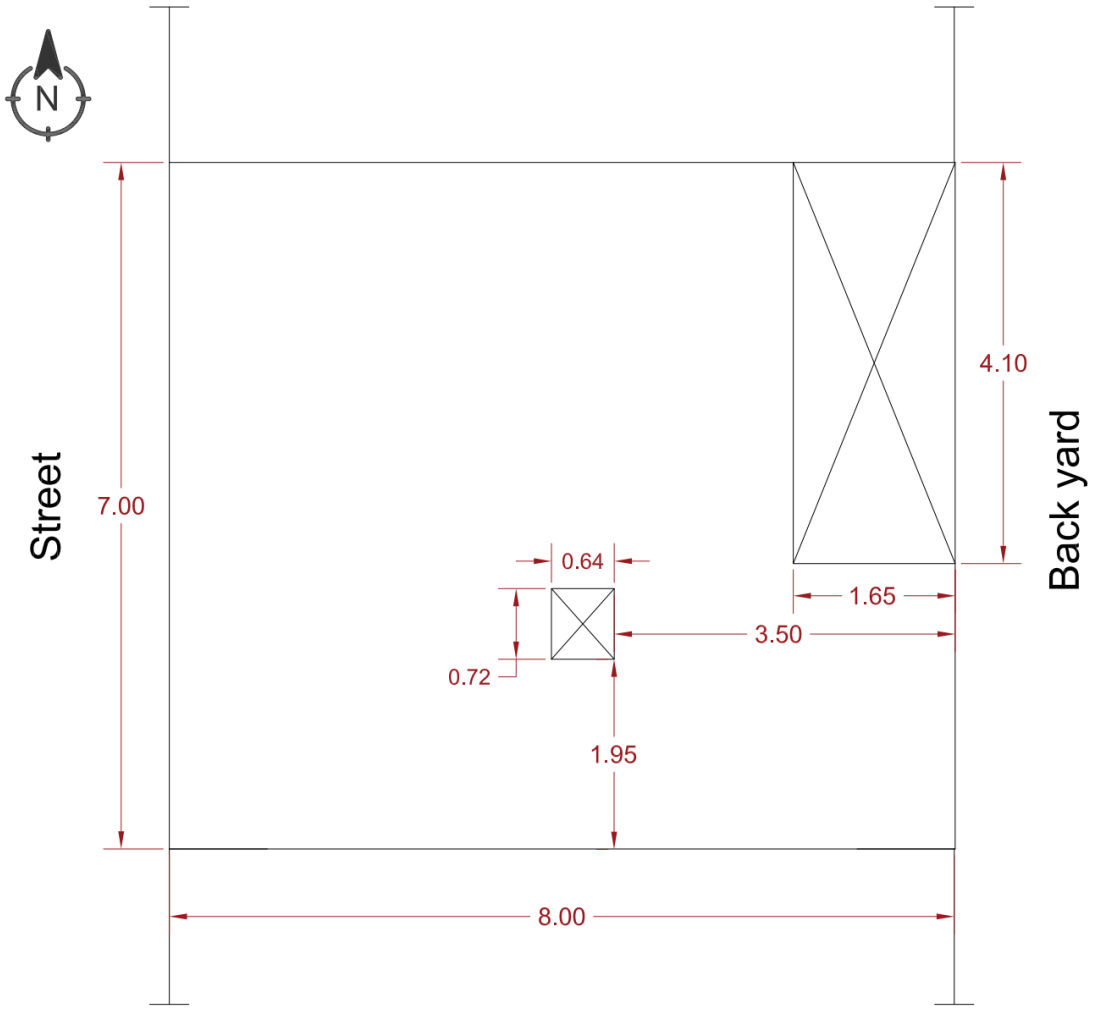
Alternative mounting systems for installing PV panels on the roof of the desired building are provided by taking into account building conditions and the available roof area without moving the chimney, water tank, and solar water heater. Standards of mountings systems such as the allowable height of the mounting system, the required distance between the mounting system and the edge of the roof, the appropriate tilt angle of the panels, preventing the shadows of the panels on each other by considering the proper distance between the arrays, the symmetrical arrangement of the panels, and maintaining the aesthetics of the building are taken into account, which are mentioned below:

- Height of the mounting system: 1.1 meters
- Distance from the edge of the roof: 1 meter
- Tilt angle: 31 °
- Distance between arrays > 90 cm

The available area on the roof for the installation of PV panels and the arrangement of roof furniture, including the chimney, water tank, and solar water heaters is shown in (Figure 47).

Figure 47

Plan View of the Roof



Based on the evaluations performed and taking into account the standard points and the available roof area and the arrangement of the roof furniture, the maximum number of PV panels that can be installed on the roof of this structure is 16 panels. Two alternative mounting systems have been developed taking into account analysis results of previous models in this study. These alternative mounting systems are designed to carry 16 PV panels in 3 arrays. The length of one array of the mounting system is 6 meters and the other two arrays are 5 meters. The difference between the two alternatives is the span length of the beams.

(Figure 48) and (Figure 49) show how the arrays of the alternative mounting systems are arranged on the roof.

Figure 48

Plan View of the PV Panels Arrangement in Alternative Models

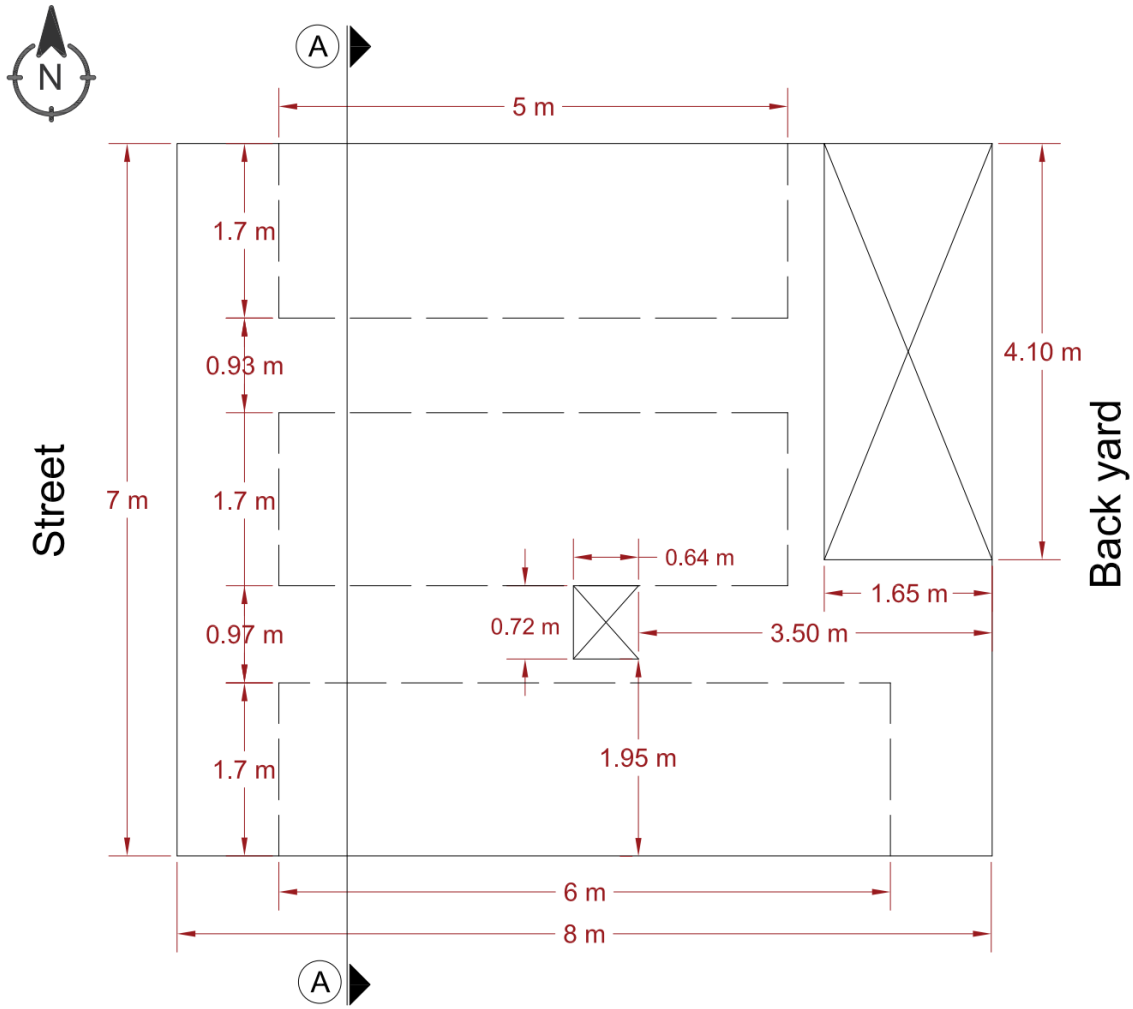
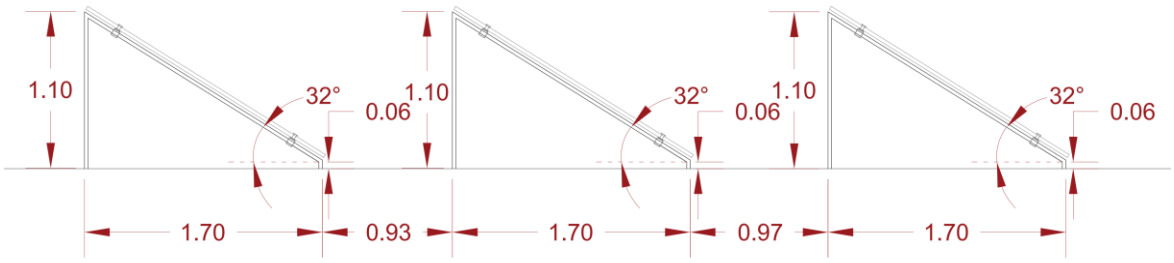


Figure 49

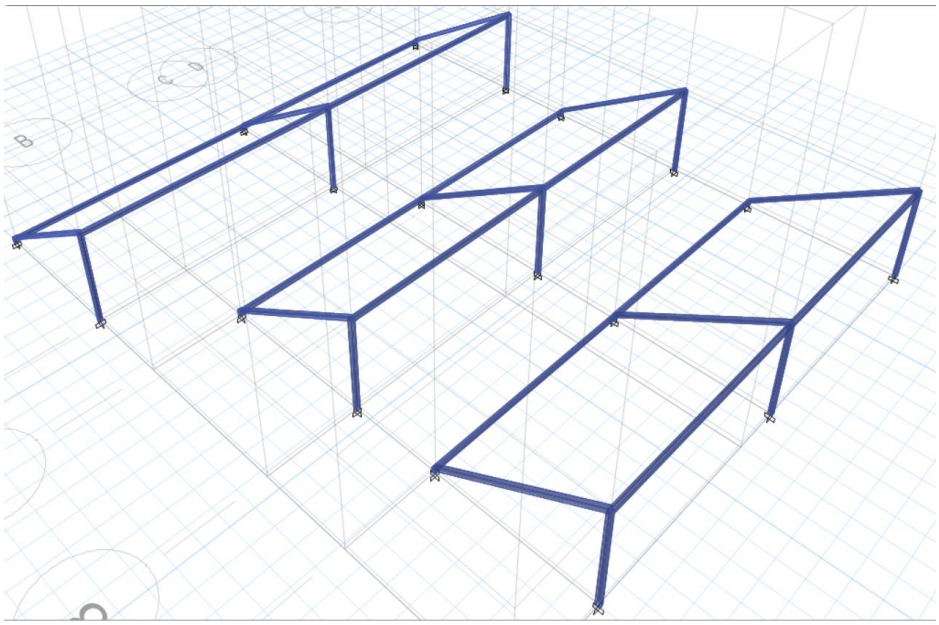
Section A-A of the PV Panels Arrays in Alternative Models



The first alternative mounting system. In this alternative mounting system, the span length is 3 meters for the 6-meter array and 2.5 meters for 5-meter arrays. The mounting system and arrangement of the arrays are shown in (Figure 50).

Figure 50

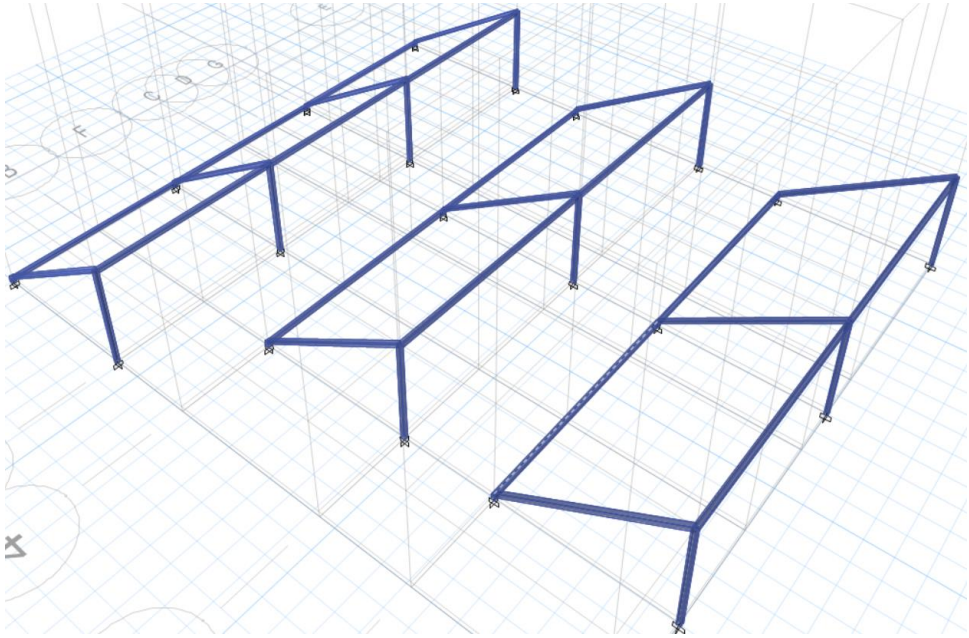
The First Alternative Mounting System



The second alternative mounting system. In this alternative mounting system, the span length is 2 meters for the 6-meter array and 2.5 meters for 5-meter arrays. The mounting system and arrangement of the arrays are shown in (Figure 51).

Figure 51

The Second Alternative Mounting System



The alternative mounting systems are designed with software and are compared in terms of weight, cost, and aesthetics. Finally, the optimum mounting system is recommended for installing PV panels on the roof of a building.

Review of Standards

Advances in technology have always necessitated the enactment of new rules and regulations to ensure system efficiency and optimal performance, maintain the safety of systems and individuals, and prevent financial losses. The standard for installing rooftop PV panels in Nicosia, Northern Cyprus has been established on July 1, 2021.

Many countries and cities around the world have established standards for the installation of PV panels in recent years, some of which have many commonalities and, in some cases, vary according to local conditions. But it is important to pay attention to the details that affect the performance and efficiency of the panels, safety, longevity, aesthetics, landscape, and harmony of PV panels with urban architecture, both in the long term and in the short term.

This study reviews some of the standards and guidelines of different countries in the world regarding rooftop panel PV panel mounting systems and compares them with the standards of rooftop panel PV panel mounting systems in Northern Cyprus.

Then, given the current state of PV panel installation systems, the existing problems and concerns, local conditions in Northern Cyprus that affect the installation of PV panels, and the regulations governing PV panels in the world and in Northern Cyprus, recommendations are made to improve the standards governing rooftop PV panel mounting systems in Northern Cyprus.

CHAPTER IV
Findings and Discussion

The findings of the study are outlined and discussed in this chapter. First, the findings of the collected data and interviews are reviewed, then wind loads are calculated based on two different standards and compared with each other. Afterward, a number of mounting systems of PV panels are designed by considering some variables including the number of storeys, span length, column arrangement, and load resisting system, and the effects of these variables on the deflection of the mounting systems are investigated.

Furthermore, rooftop PV panel mounting systems designed for residential buildings are used to investigate the effects of the number of storeys, span length, and load resisting system, in three areas, including the cost of the mounting system, aesthetics, and the weight of the mounting system.

Then, the results of inspections and modelling of the case study by the software are presented, weaknesses and issues are investigated, and alternative mounting systems are provided in accordance with the building condition and relevant standards.

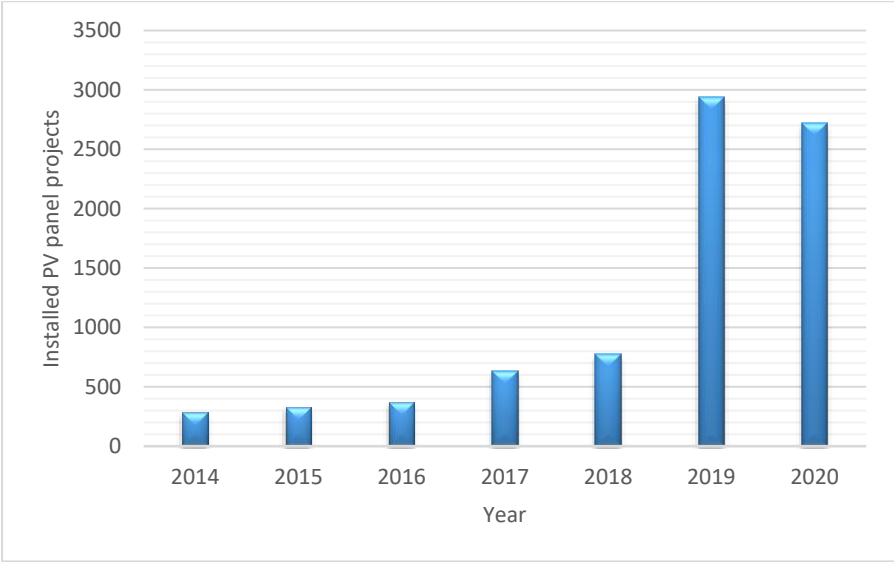
Finally, some standards and guidelines from different countries regarding rooftop PV panel mounting systems are reviewed and compared with the standards of rooftop PV panel mounting systems in Northern Cyprus, and recommendations are made to improve the standards governing rooftop PV panel mounting systems in Northern Cyprus.

Findings and Discussion of Collected Data

According to data collected from KIB-TEK, 285 rooftop PV panel projects were completed in 2014 in Northern Cyprus, while 2,724 rooftop PV panel projects were completed in 2020. The total number of rooftop PV panel projects in Northern Cyprus was 8,539 cases as of April 11, 2021. (Figure 52) depicts the number of rooftop PV panel projects carried out from 2014 to 2020 in Northern Cyprus.

Figure 52

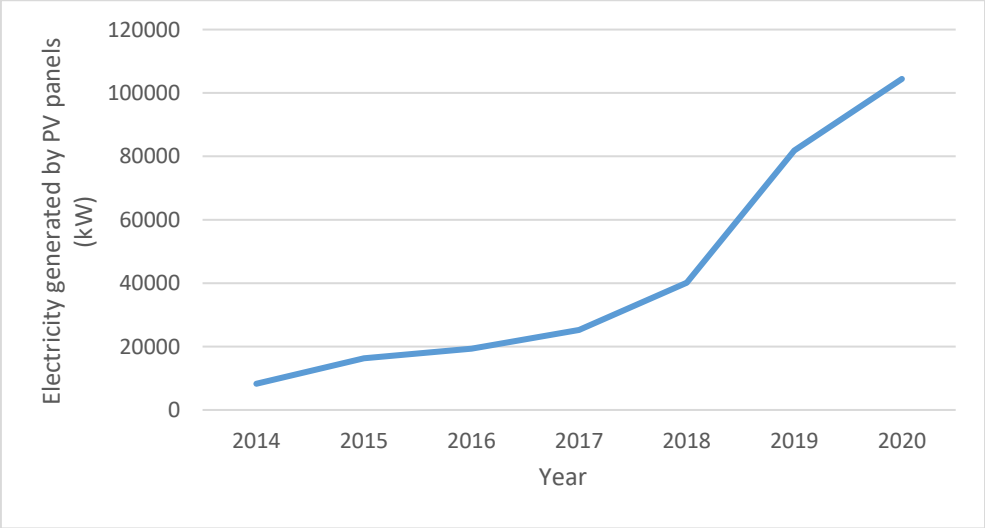
Number of Installed PV Panel Projects Per Year in Northern Cyprus



As shown in (Figure 52), the number of rooftop PV panel projects was rapidly increasing which was leading to increased power generation. The total electricity generated by PV panels in Northern Cyprus from 2014 to 2020 is shown in (Figure 53).

Figure 53

Electricity Generated by PV Panels Per Year in Northern Cyprus



The results of interviews with PV panel installation companies show that:

- All companies have refused to install PV panels on the roofs of old buildings that do not look to be able to withstand the loads associated with PV panel systems, including the weight of the panels, the related pieces of equipment, and the mounting system.
- Roof orientation has always been considered and companies have attempted to design a mounting system to install the panels face to the south even on inclined roofs
- Most companies do not consider the effects of different tilt angles on the efficiency of PV panels.
- Most companies have made effort to reduce the shadows on rooftop PV panels.
- All companies have taken into account the available area on roofs and the arrangement of other roof furniture, including chimneys, solar water heating panels, tanks, etc.
- None of the companies have considered the effects of building height on the design of the PV panel mounting system.
- All companies stated that there are no regulations governing the installation structure of PV panels.
- Few companies have considered the aesthetic impacts of PV panels on buildings and cities.

In addition to PV panel installation companies, thirty-two users of rooftop PV panels were interviewed and were asked about their experiences.

Table 12

Responses of PV Panel Users to the Conducted Interviews

Criteria	Description	Result
Mounting system problems	Mounting system problems	Some participants reported that mounting systems had problems during or after installation, and in some cases, even the panels were damaged due to improper mounting systems.
Side effects of mounting systems	Roof problems	Many participants stated that the roof did not have any problem after installing the PV panels, however,

Criteria	Description	Result
		few users mentioned that problems such as water leakage were caused by the installation of the panels.
	Impact on aesthetic	The majority of participants stated that PV panels have negative impacts on the aesthetics of their building, although some stated that this is not a major issue, others said that they are dissatisfied with the appearance of the building after installing PV panels but have no alternative.
User concerns	Concerns about maintenance	Most participants did not worry about maintaining PV panels.
	Concerns about PV panels on very windy days	Most participants, particularly those who had experienced structural and panel failure, were concerned about the PV panels on windy days.
	Occasional inspection of the panels and concerns about their condition	Many participants stated that they regularly check the panels, especially after windy days, to make sure everything is working properly.

As mentioned earlier, electricity production in Northern Cyprus is currently largely dependent on non-renewable resources. But despite the problems mentioned by users, the tendency to use rooftop PV panels in Northern Cyprus is increasing dramatically. It seems that public attention to the harms of using fossil fuels, public awareness of electricity generation by PV panels, the rapid growth of global per capita electricity consumption, advertising, rising electricity prices, and the expansion of installation companies and related services in this country are the reason for the increase in the number of installed PV panels and the tendency to install them.

According to data collected from YEK, there were 82 PV panel installation companies in Northern Cyprus as of April 2021.

Wind Load Calculation

As previously described, wind loads were calculated based on two different standards, TS498 and ASCE 7-16 for mounting systems of PV panels. The following are the results of wind load calculations based on each of these standards. Besides, uplift wind loads and downward wind loads calculated based on each of the standards are compared with each other.

Wind load calculations based on TS498

The wind loads calculated based on TS498 are shown in (Table 13) and (Figure 54) for the roof-mounted structure of PV panels. As mentioned in Chapter 3, wind load calculations based on TS498 do not depend on the beam span length, and the wind loads are calculated for two different building heights (3-storey and 7-storey buildings).

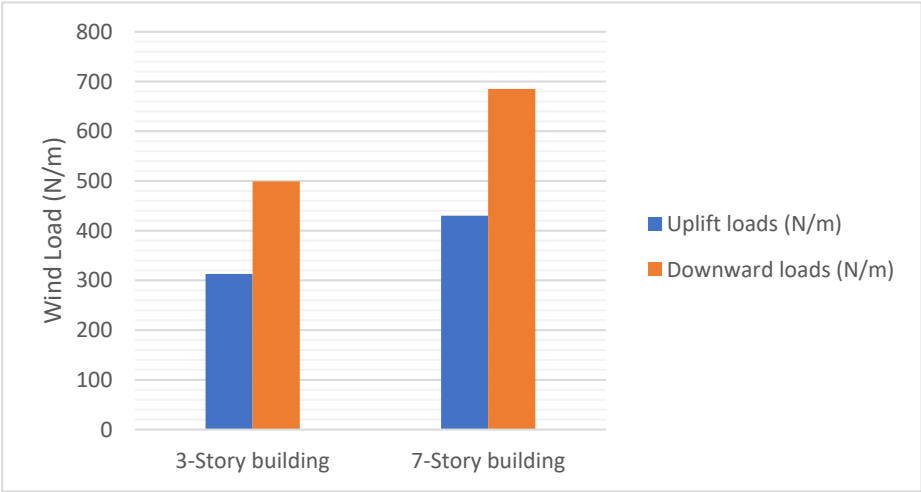
Table 13

Wind loads on Rooftop PV Panel Mounting Systems Based on TS498

Span length	**Wind load direction**	**Number of storeys**	
		3-storey building	**7-storey building**
For all span lengths	Uplift loads (N/m)	313	430
	Downward loads (N/m)	499	685

Figure 54

Wind Loads on Rooftop PV Panel Mounting Systems Based on TS498



As shown in (Figure 54), the wind load increases with increasing building height, and according to TS498, the downward wind load on the rooftop PV panel mounting system is significantly greater than the uplift load for each building height.

Wind load calculations based on ASCE 7-16

(Table 14), (Figure 55) and (Figure 56) show the uplift wind loads and downward wind loads on 3-storey and 7-storey buildings with 8 different span lengths of rooftop PV panel mounting systems.

Table 14

Wind Loads on Rooftop PV Panel Mounting Systems Based on ASCE 7-16

Span length (m)	**Wind load direction**	**Number of storeys**	
		3-storey building	**7-storey building**
1	Uplift loads (N/m)	889	1463
	Downward loads (N/m)	592	975
1.5	Uplift loads (N/m)	741	1217
	Downward loads (N/m)	497	809
2	Uplift loads (N/m)	713	1153
	Downward loads (N/m)	478	769
2.5	Uplift loads (N/m)	691	1091
	Downward loads (N/m)	461	729
3	Uplift loads (N/m)	663	1061
	Downward loads (N/m)	442	706
3.5	Uplift loads (N/m)	641	985
	Downward loads (N/m)	428	657
4	Uplift loads (N/m)	591	935
	Downward loads (N/m)	392	625
4.5	Uplift loads (N/m)	542	901
	Downward loads (N/m)	361	602

Figure 55

Wind Loads on Rooftop PV Panel Mounting Systems For 3-Storey Building Based on ASCE 7-16

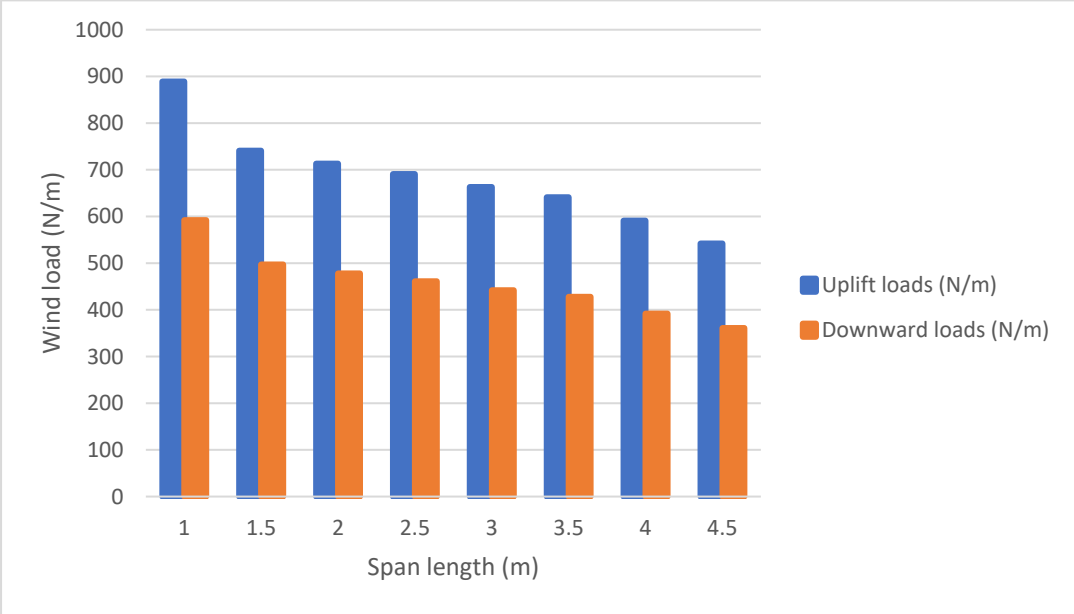
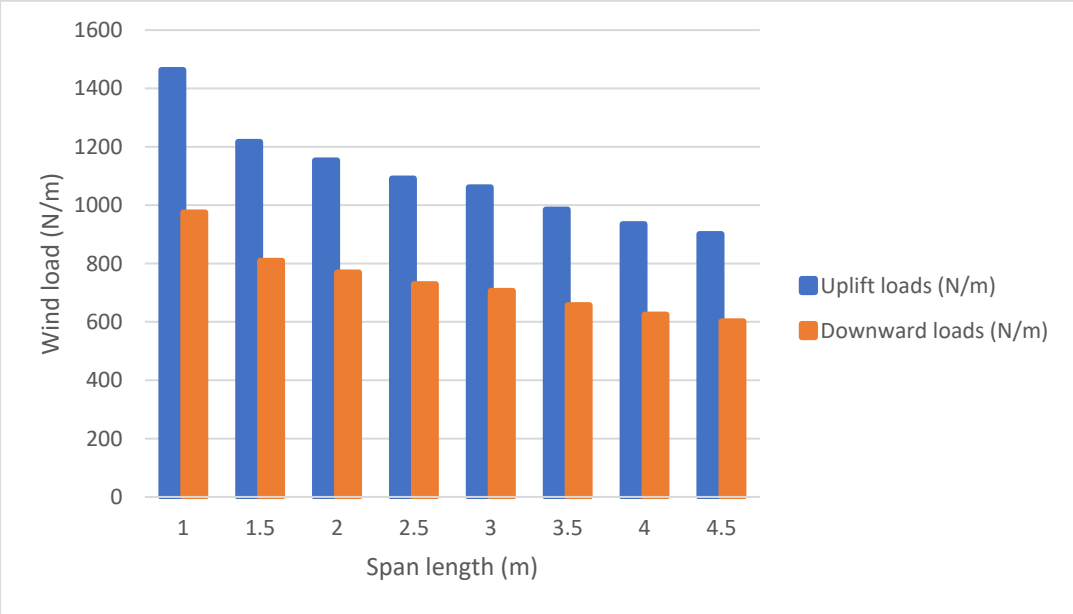


Figure 56

Wind Loads on Rooftop PV Panel Mounting Systems For 7-Storey Building Based on ASCE 7-16



As shown in the figures, the downward wind load on PV panels is significantly less than the uplift load for each building height in accordance with ASCE7-16. In addition, increasing the span length increases the effective wind area, and increasing

the effective wind area reduces the nominal net pressure coefficient and thus reduces the wind load (see Appendix A). Therefore, wind load decreases with increasing the span length of mounting systems.

Comparison of Wind Loads Calculated Based on TS498 and ASCE 7-16

In the following figures, the uplift and downward wind loads for 3-storey and 7-storey buildings based on TS498 and ASCE7-16 have been shown.

Figure 57

Uplift Wind Load (3-Storey Buildings)

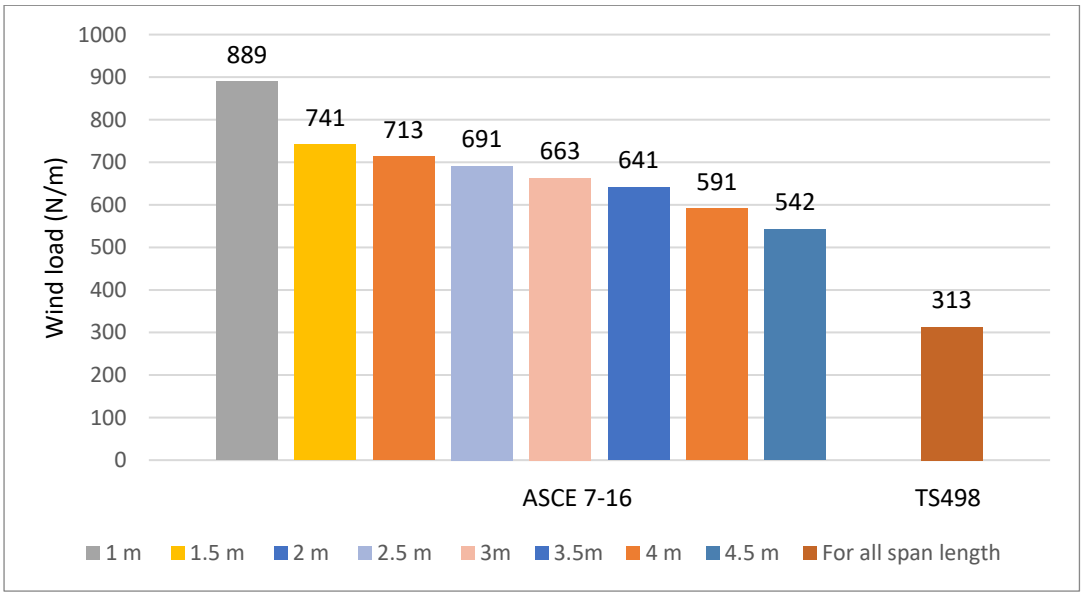


Figure 58

Downward wind load (3-Storey buildings)

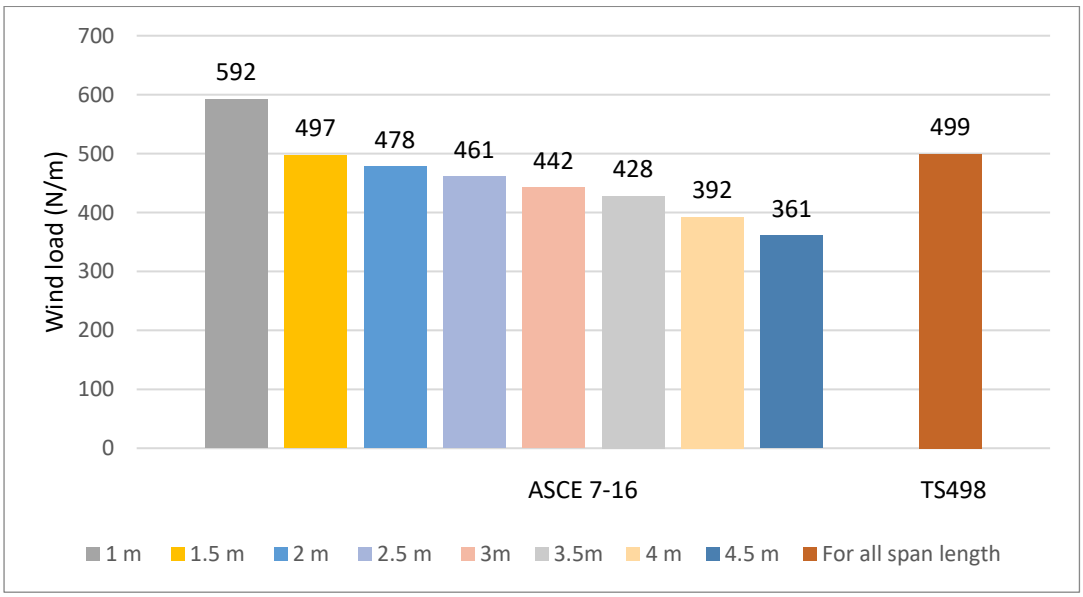


Figure 59

Uplift wind load (7-Storey buildings)

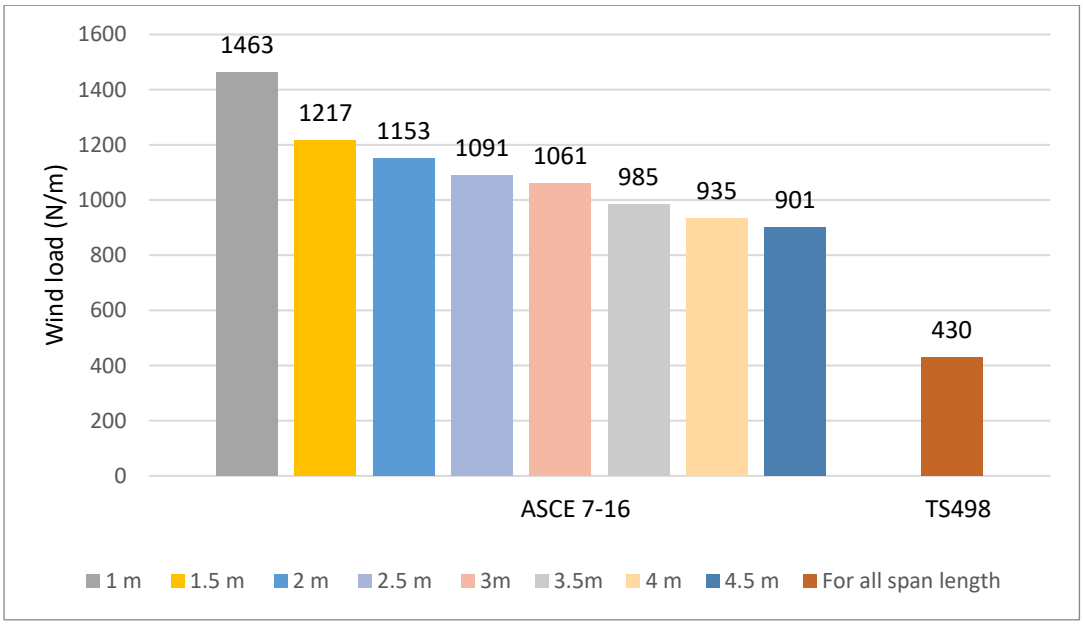
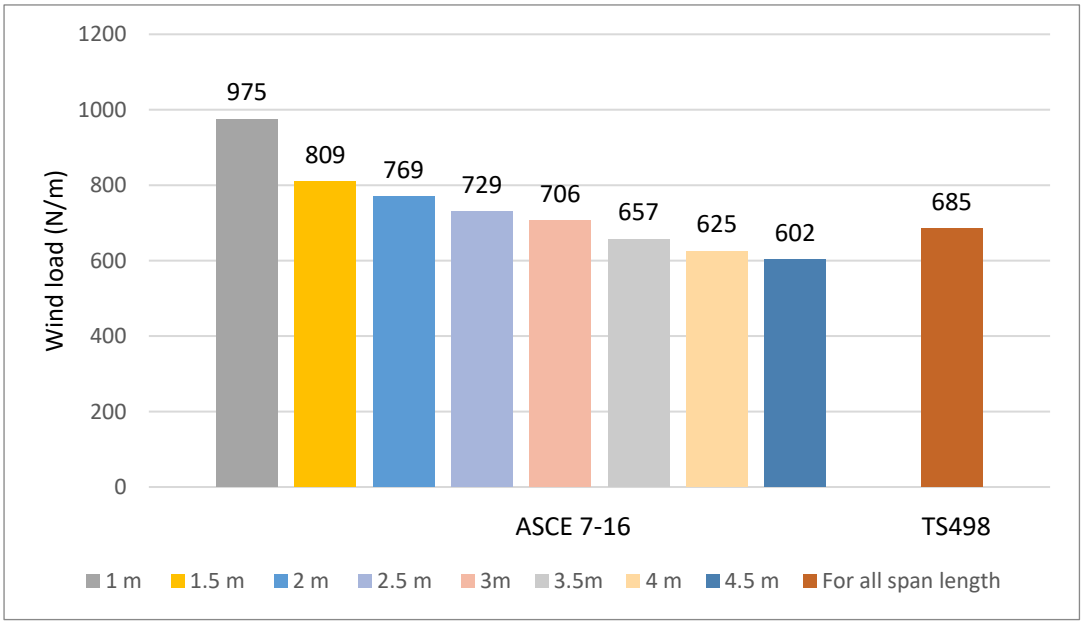


Figure 60

Downward wind load (7-Storey buildings)



- A comparison between the two standards shows that while TS498 provides equal wind loads for all span lengths of mounting systems when all other variables are constant, span length is an effective parameter in calculating wind load based on ASCE 7-16.

- According to TS498, the downward wind load on PV panels is significantly greater than the uplift load for any building height, but according to ASCE 7-16, the downward wind load on PV panels is significantly less than the uplift load for any building height and span length.
- Load calculations based on TS498 offer smaller uplift wind loads than ASCE 7-16, while downward wind loads calculated based on TS498 are in the range of ASCE 7-16.

Mounting systems that support PV panels are often lightweight structures, therefore wind loads can greatly affect them. On the other hand, since PV panel mounting systems have no walls or barriers, winds can easily create uplift loads on the systems and have significant effects on them.

TS498 does not provide specialized wind load calculations for rooftop PV panel mounting systems, and wind loads are calculated with the same variables and the same approach on different buildings, including residential, commercial, industrial, and other structures. Therefore, wind loads on rooftop PV panel mounting systems are calculated the same as wind loads for closed structures such as residential buildings, where the uplift wind load is low. As a result, the downward wind load is greater than the uplift wind load when wind loads on the PV panel mounting system are calculated according to this standard.

On the other hand, ASCE 7-16 provides wind loads on various structures using a variety of approaches and parameters and specifically provides wind load calculation methods for rooftop PV panel mounting systems, therefore the effect of the uplift wind load is well considered in this standard.

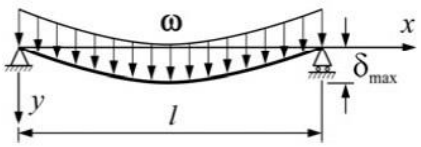
Therefore, wind loads calculated based on TS498 and ACSE 7-16 are different from each other. The wind load calculated in accordance with ASCE 7-16 seems to be more reliable with respect to the parameters and variables considered and the proposed method for calculating wind load on rooftop PV panels, therefore in the models, the wind loads are calculated using ASCE 7-16.

The Effect of Different Variables on the Deflection of Mounting Systems

In general, the type and size of loads on the beam, the type of end joints of the beam, the length of the beam, the modulus of elasticity (E), and the moment of inertia (I) of the beam section affect the deflection (δ) of the beam.

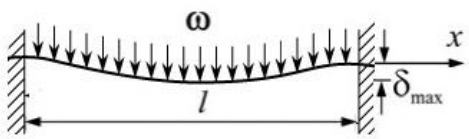
Wind load and dead load are uniform loads applied to the mounting systems of PV panels along the beams and the modulus of elasticity and moment of inertia of the beams are constant along the beams. Therefore, in any situation, the maximum deflection is in the middle of the beam. The deflection formulas for each type of end connection of beams are as follows.

- Beam simply supported at ends



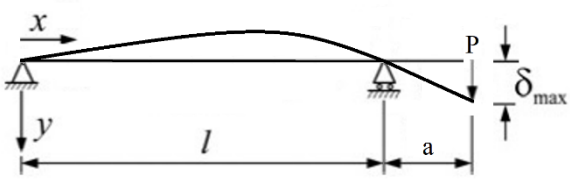
$$\delta_{max} = \frac{5\omega l^4}{384EI}$$

- Beams fixed supported at ends



$$\delta_{max} = \frac{\omega l^4}{384EI}$$

As mentioned, wind and dead loads are uniform loads applied to the horizontal beams, which are connected to the inclined beams. In type B of column arrangement, there are overhanging beams. The modulus of elasticity and moment of inertia of the beams are constant along the beams. The deflection formula for overhanging beams in accordance with the loading condition is as follows:



$$\delta_{max} = \frac{P\alpha^2}{3EI}(l + a)$$

In the following, the parameters considered in this study to control their effects on the deflection of mounting systems and the related results are presented. These results are obtained based on the 32 general models described in Chapter 3.

Number of storeys

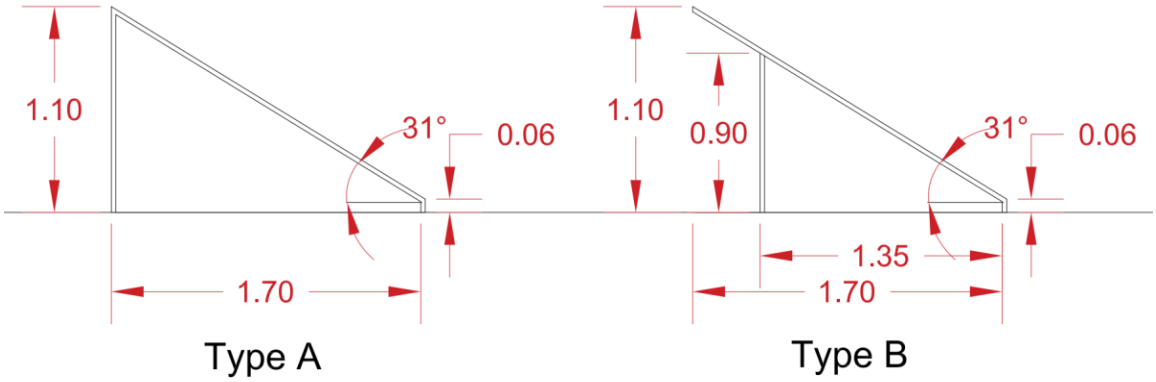
There is a strong relationship between wind load and building height. As shown in (Table 13) and (Table 14), increasing the number of storeys increases both uplift wind loads and downward wind loads in accordance with TS498 and ASCE 7-16.

Arrangement of columns

As mentioned in Chapter 3, the models are designed with two different types of column arrangements. (Figure 61)

Figure 61

Section View of the Arrangement of Columns: Type A And Type B



The following figures show the deflection of the beams with different span lengths and load resisting systems while the columns are arranged with Type A and Type B.

Figure 62

Arrangement of Columns Vs. Deflection of The Beams (3-Storey Building/ Moment Frame System)

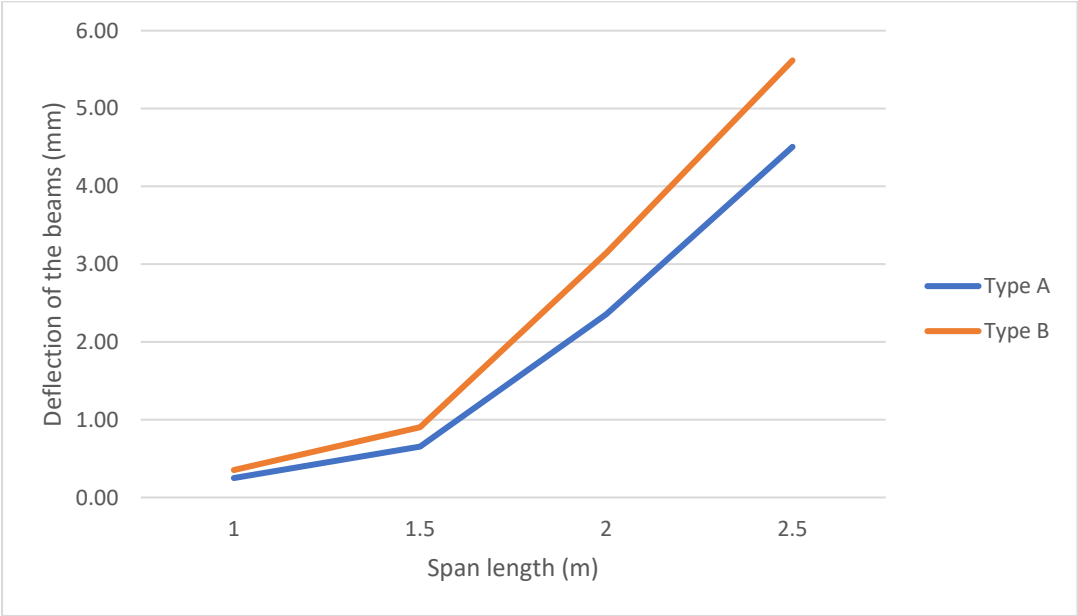


Figure 63

Arrangement of Columns Vs. Deflection of The Beams (7-Storey Building/ Moment Frame System)

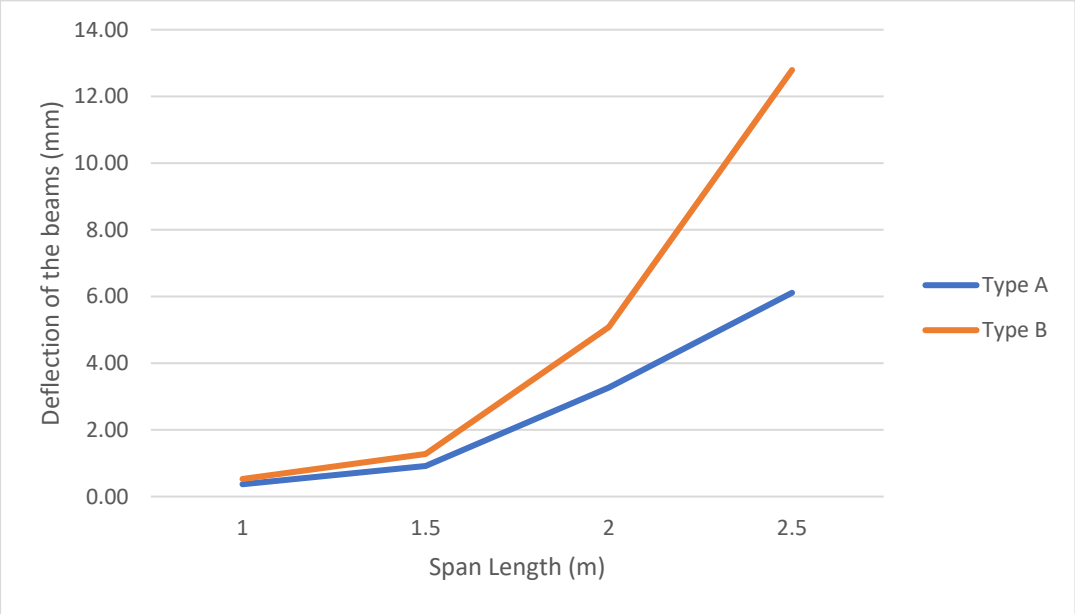


Figure 64

Arrangement of Columns Vs. Deflection of The Beams (3-Storey Building/ Bracing System)

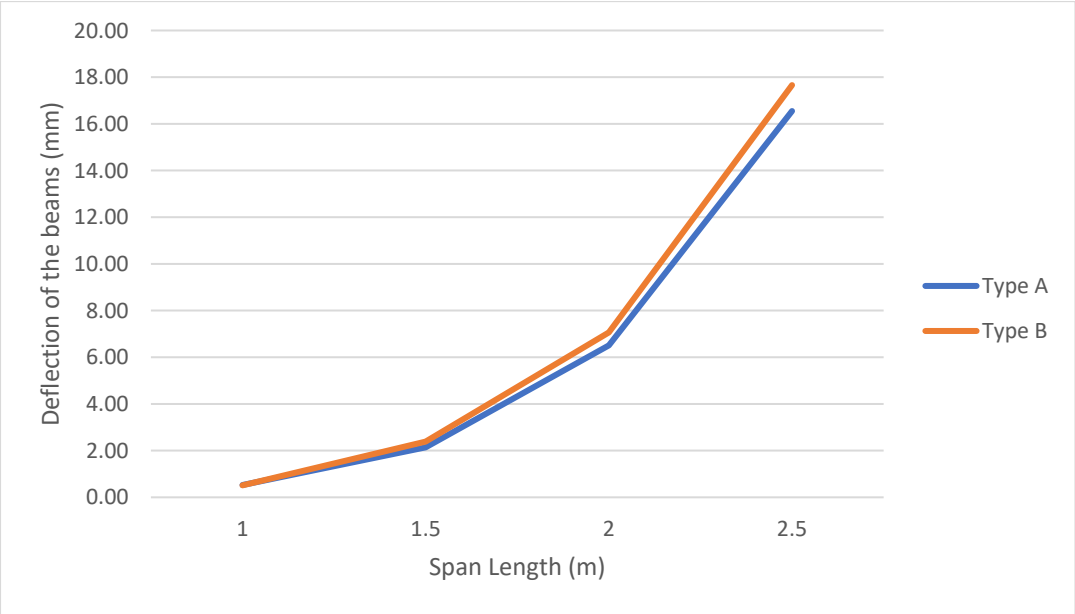
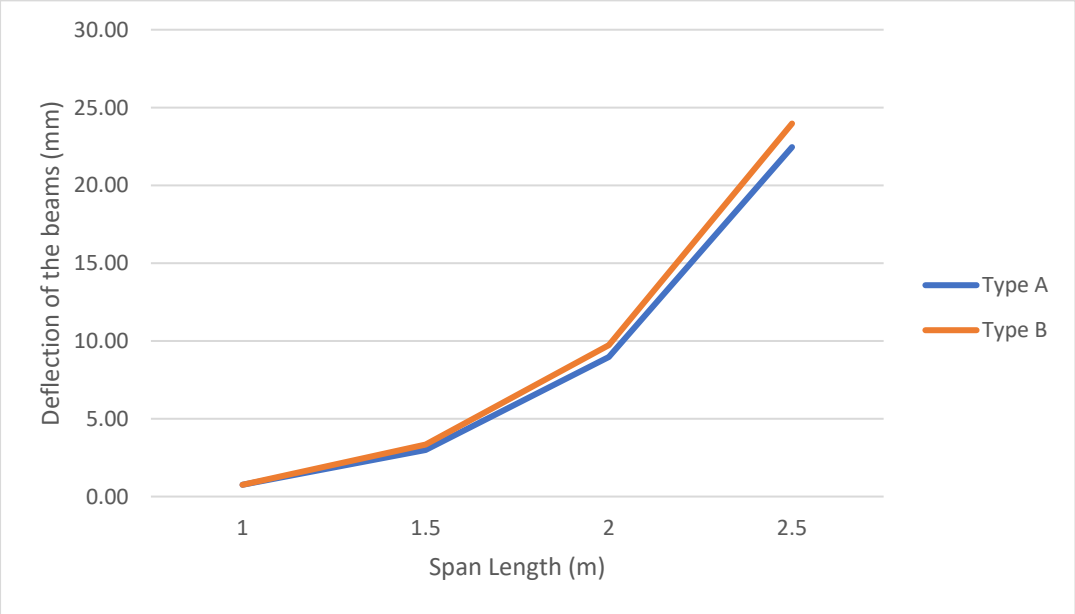


Figure 65

Arrangement of Columns Vs. Deflection of The Beams (7-Storey Building/ Bracing System)



As shown in the figures, Type A of column arrangement causes less deflection than Type B. In other words, when the columns are placed in the corner of the structure (Type A), the columns support the beams better and the deflection of the beams is reduced. Therefore, when the span length, height of the structure, load resisting system, and sections of the structural elements are the same, models with Type A columns arrangement have less deflection than Type B columns arrangement.

In addition, increasing the span length increases the effects of column arrangement on the deflection, and on the other hand, increasing the span length causes a greater deflection difference between Type A and Type B.

Span length

Increasing the span length reduces the number of columns, but based on the corresponding formula, the length has a power of 4, therefore, increasing the span length increases the deflection dramatically, and therefore, stronger sections are needed to control the deflection of the structure.

It should be noted that increasing the span length affects the effective wind area and reduces the wind load based on ASCE 7-16, but the span length has a power of 4 in the deflection formula. Thus, although wind loads decrease by increasing the span length, increasing the span length ultimately increases the deflection of the beams.

Load resisting system

As mentioned before, mounting systems are designed with two different types of load resisting systems, which are the bracing system and the moment frame system. The effects of each type of load resisting system on the deflection of the beams are shown in the following figures.

Figure 66

Load Resisting System Vs. Beams Deflection (3-Storey Building/ Type A)

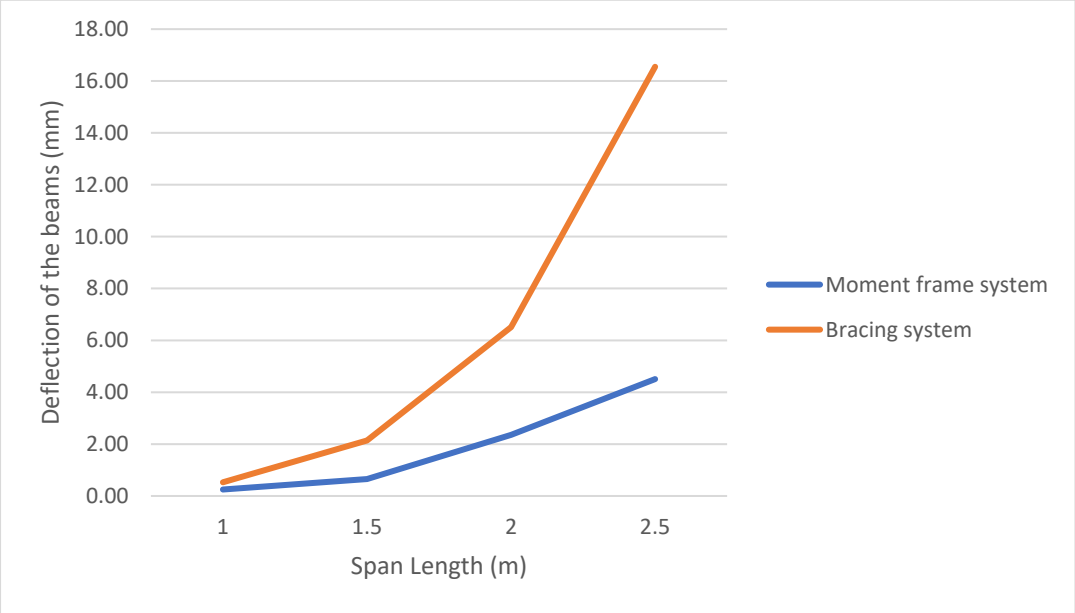


Figure 67

Load Resisting System Vs. Beams Deflection (7-Storey Building/ Type A)

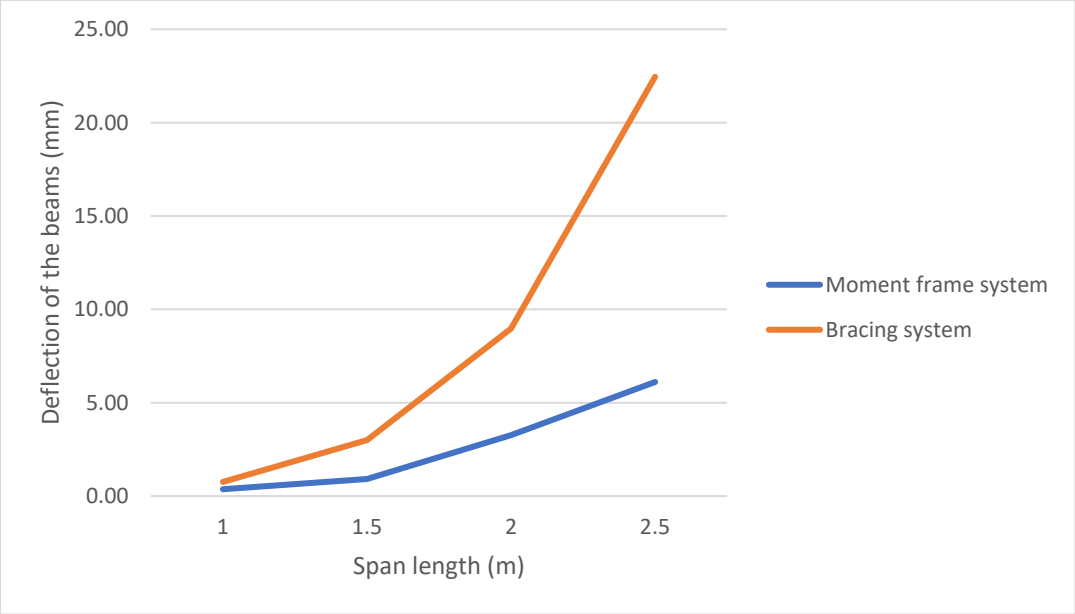


Figure 68

Load Resisting System Vs. Beams Deflection (3-Storey Building/ Type B)

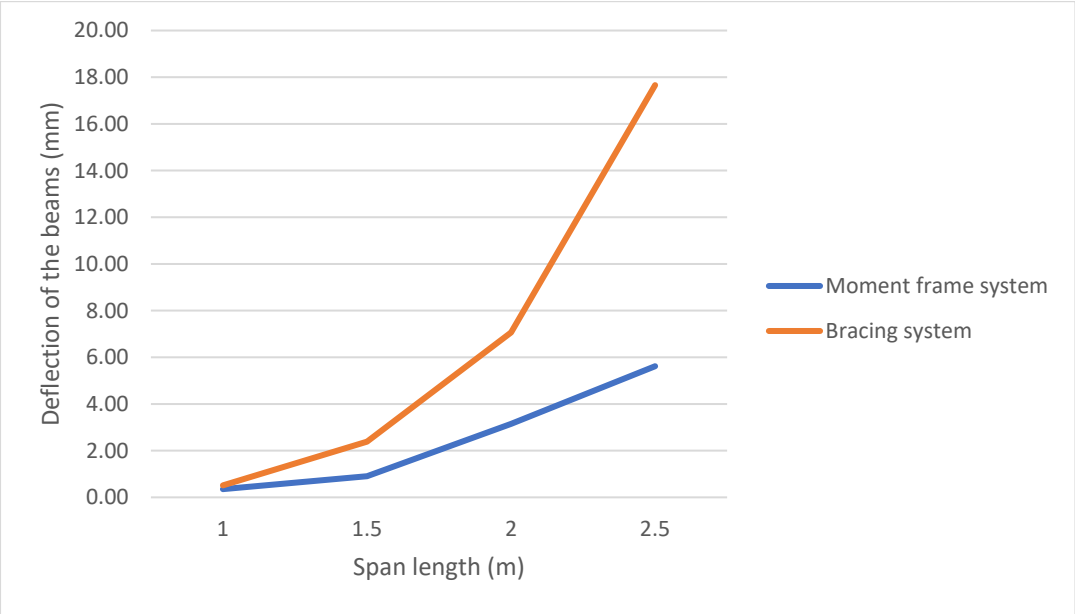
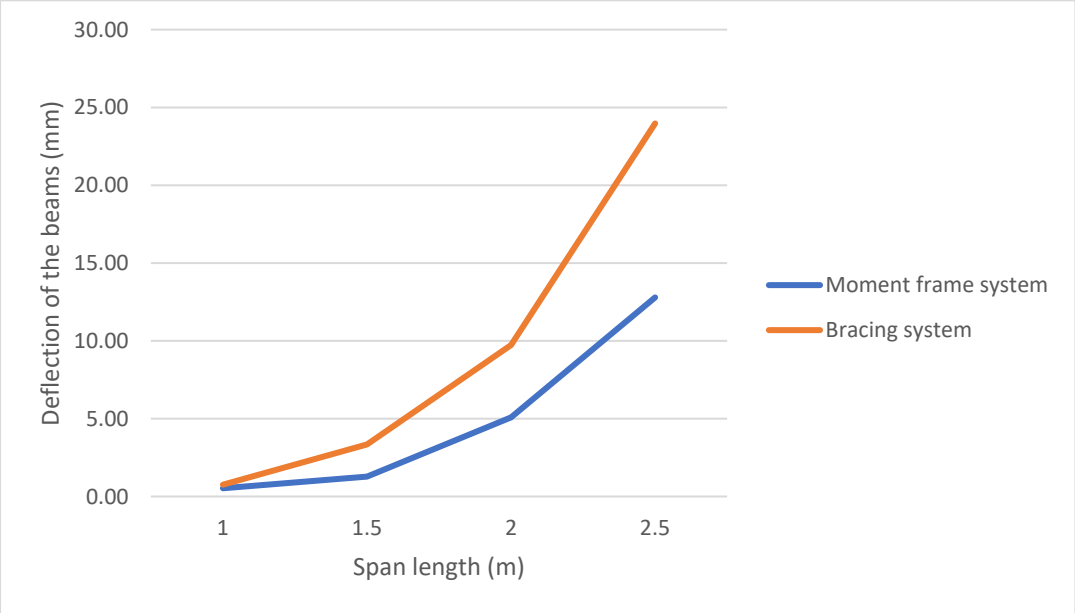


Figure 69

Load resisting system vs. beams deflection (7-Storey building/ Type B)



As shown in the figures, while the span length, the height of the structure, column arrangement, and the section of the structural elements are the same, the structures designed using the moment frame system experience less deflection than structures designed using the bracing system, especially in larger span lengths.

Furthermore, increasing the span length increases the effects of the load resisting system on the deflection.

Modelling 32 general models of rooftop PV panel mounting systems reveals that the Type B arrangement of columns decreases the required materials by 4% to 7%, but increases the deflection of the beams, which leads to an increase in the size of the required steel profile sections to control the deflection of the beams. Therefore, Type A of column arrangement creates less deflection with the same steel profile sections than Type B, which reduces the weight and cost of the mounting system.

Deflection of the beams in mounting systems is highly limited due to possible damage to PV panels and destruction of PV cells. Therefore, when mounting systems are designed using bracing systems, larger steel profile sections are needed to control the deflection of the beams, which increases the total weight and cost of the mounting system. Therefore, designing mounting systems using a moment frame system is a better choice which results in less cost and less weight of the structure.

Controller Load Combinations

In this study, 37 load combinations are used as mentioned in Chapter 3. According to the results of the analysis of 32 general models, the maximum deflection for all models is due to the combination number 2 which is "$1.2D + W_d$". Where, W_d is the downward wind load and D is the dead load.

As mentioned earlier, increasing the weight of the structure increase the effect of seismic loads. In other words, when the circumstances of two structures are perfectly the same, the heavier structure is more affected by seismic loads. On the other hand, lightweight structures are affected deeply by the wind load. The mounting systems of PV panels are lightweight structures and as the results showed, the wind load in the deflection of the PV panel mounting system is more critical than the seismic load and the maximum deflection is caused by wind load and dead load. Therefore, wind load and its effects on PV panels and mounting systems, especially panels that are installed on tall buildings, should be given special attention and cannot be ignored.

Mounting Systems for Residential Buildings

As mentioned before, two different types of flat-roofed residential buildings with the same available roof area but different orientations to the north have been considered and rooftop PV panel mounting systems have been designed to be installed

on the roof of these buildings. The results of the analysis of Type I and Type II mounting systems are as follows.

Type I

16 models of mounting systems have been developed to support 56 PV panels (7 rows of 8 panels) on the roof of Type I residential buildings and compared in terms of the weight of the mounting system, cost of the mounting system, and aesthetics.

✓ **Weight of the mounting system.**

The weight of the rooftop mounting systems of PV panels is of particular importance because these mounting systems are usually installed on the roofs of buildings that have already been constructed and the loads associated with these panels have not been included in the design of the building. As a result, designing a safe and lightweight mounting system is preferred. The weight of each mounting system with different span lengths, different building heights, and different load resisting systems is shown in (Figure 70) and (Figure 71).

Figure 70

Weight of the Mounting System Vs. Span Length (3- Storey Building)

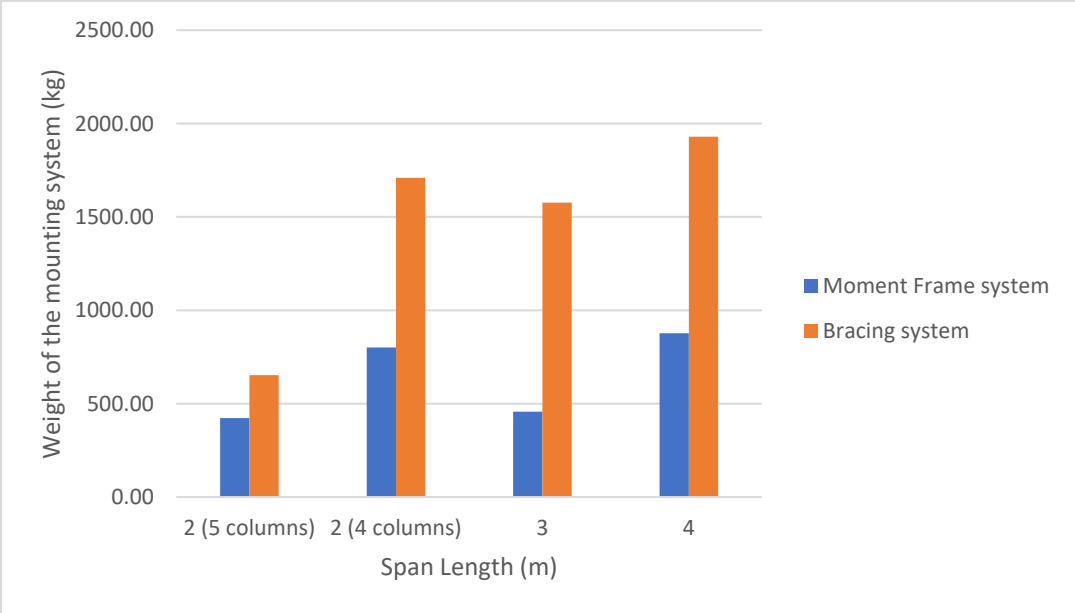
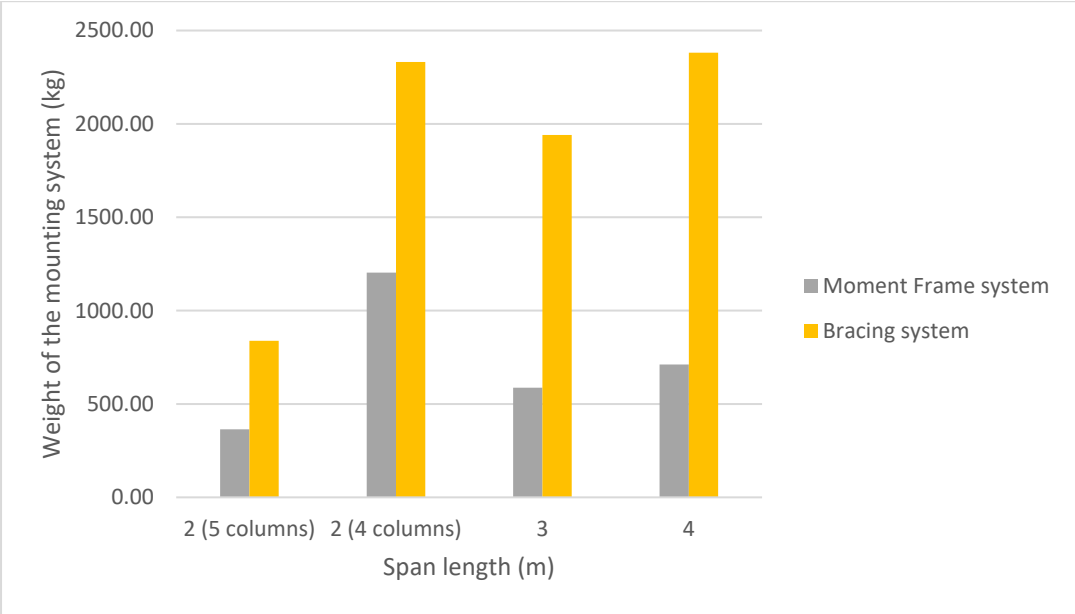


Figure 71

Weight of the mounting system vs. span length (7- storey building)



According to the above figures, the following results can be found:

- Using the moment frame system reduces the weight of the entire mounting system compared to the bracing system.
- Increasing the span length reduces the number of columns, but larger sections are needed to control the deflection of the mounting system, resulting in an increase in the weight of the entire mounting system.
- Models with a span length of 2 meters and 5 columns do not have overhanging beams, but models with a span length of 2 meters and 4 columns have 1-meter overhanging beams on each side of the mounting system. According to the results, although the use of overhanging beams reduces the number of columns, the section size increase, and the weight of the entire mounting system increases.

✓ **Cost analysis**

The cost of various steel profiles was collected from the Northern Cyprus market for this study. It should be noted that profiles with a length of 6 meters are sold and the costs are related to 6-meter profiles. Therefore, the number of profiles used for each type of mounting system is calculated, and then the cost of materials is calculated by considering the number of profiles. Cost analysis of each mounting system with different span lengths, different building heights, and different load resisting systems is shown in (Figure 72) and (Figure 73).

Figure 72

Cost Vs. Span Length (3-Storey Building)

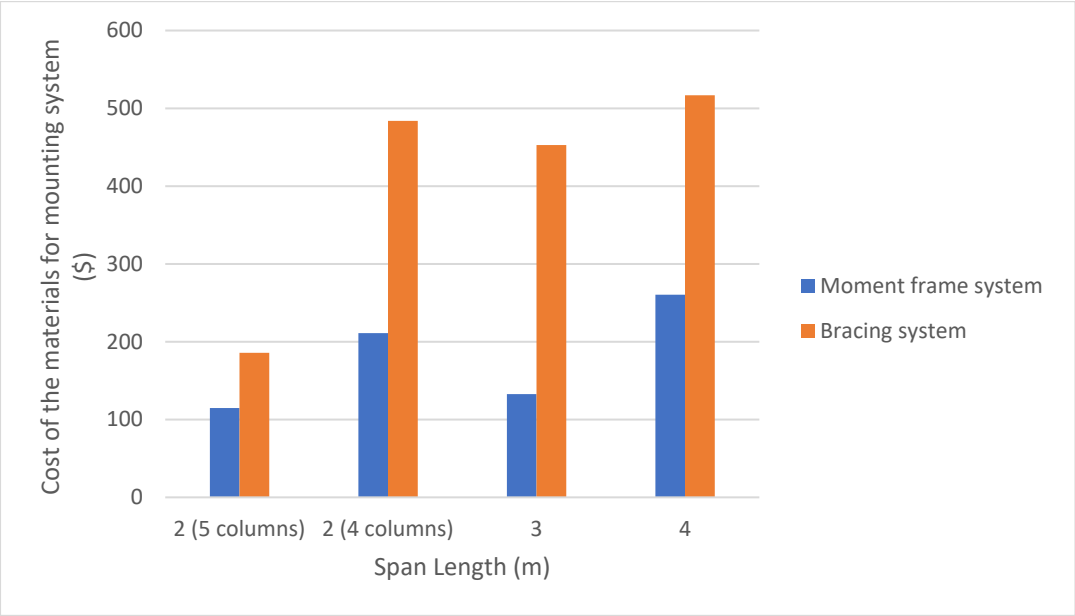
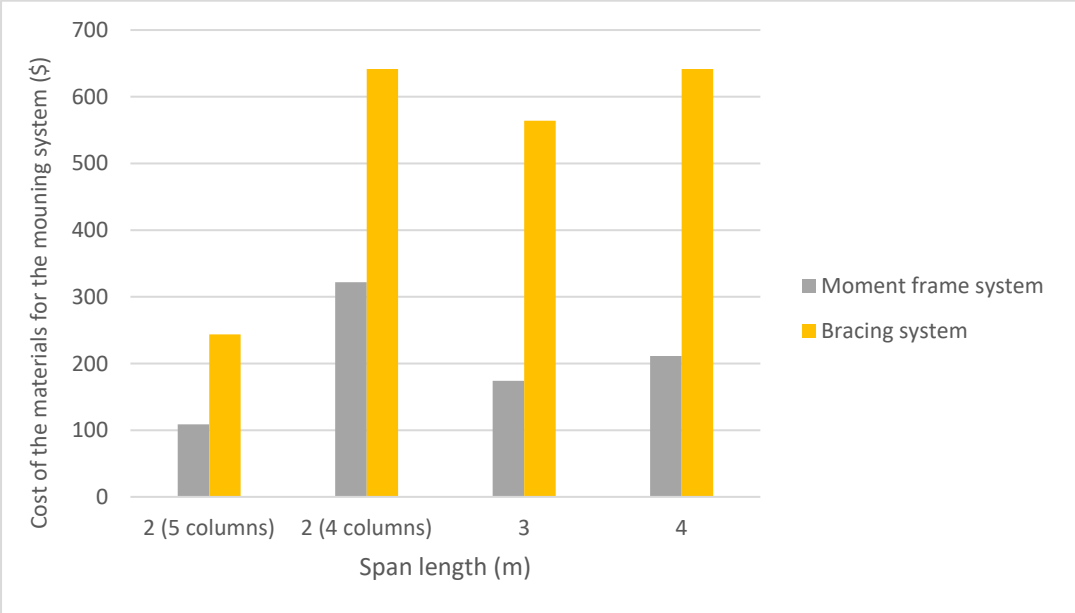


Figure 73

Cost Vs. Span Length (7-Storey Building)



According to the above figures, the following results can be found:

- When all the parameters are constant, designing the mounting system using the moment frame system is more cost-effective than using the bracing system.

- Increasing the span length reduces the number of columns and the entire length of the material, but due to controlling the deflection of the mounting system, the section size increases, which results in increasing the cost of the material.
- Models with a span length of 2 meters and 5 columns do not have overhanging beams, but models with a span length of 2 meters and 4 columns have 1-meter overhanging beams on each side of the mounting system. According to the results, although the use of overhanging beams reduces the number of columns, the size of the section increases, and with increasing section size, the cost of sections increases significantly.

Type II

16 models of mounting systems have been developed to support 54 PV panels (3 rows of 18 panels) on the roof of Type II residential buildings and compared in terms of the weight of the mounting system, cost of the mounting system, and aesthetics.

✓ **Weight of the mounting system**

The weight of each mounting system with different span lengths, different building heights, and different load resisting systems is shown in (Figure 74) and (Figure 75).

Figure 74

Weight of the Mounting System Vs. Span Length (3- Storey Building)

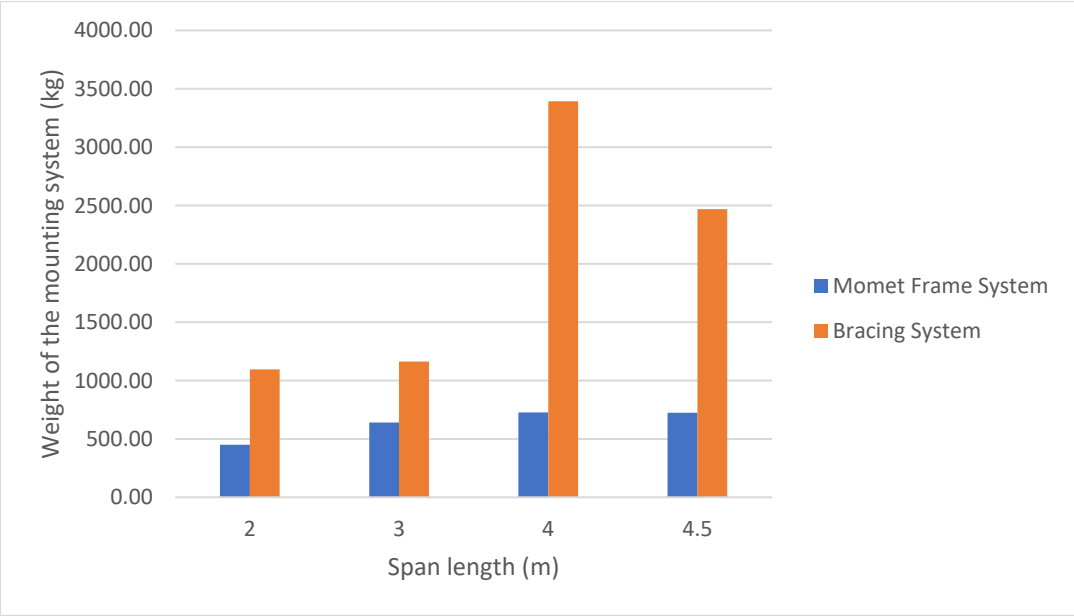
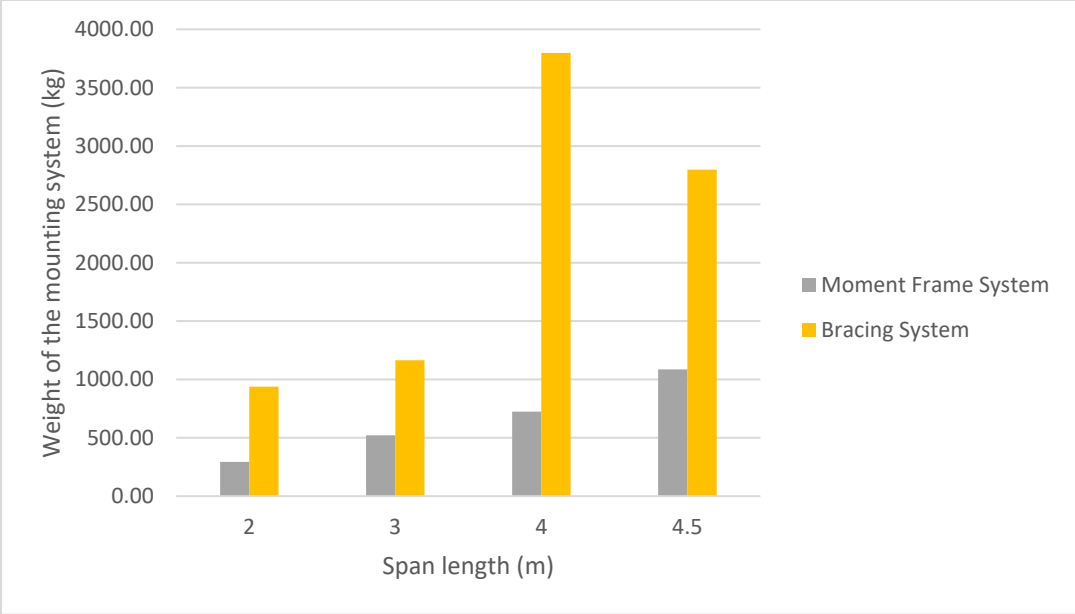


Figure 75

Weight Of the Mounting System Vs. Span Length (7- Storey Building)



According to the above figures, the following results can be found:

- Using the moment frame system reduces the weight of the entire mounting system compared to the bracing system.
- Increasing the span length reduces the number of columns, but larger sections are needed to control the deflection of the mounting system, resulting in an increase in the weight of the entire mounting system.
- Models with a span length of 4 meters have 1-meter overhanging beams on each side of the mounting system. The deflection in these overhanging beams is controlled by increasing the section size and as a result, the weight of the structure increases significantly. However, models with a span length of 4.5 meters have the same number of columns as models with a span length of 4 meters and 1-meter overhanging beams on each side, but since there are no overhanging beams, mounting systems can be designed using smaller sections. Using smaller sections decreases the weight of the entire mounting system.

✓ **Cost analysis**

Cost analysis of each mounting system with different span lengths, different building heights, and different load resisting systems is shown in (Figure 76) and (Figure 77).

Figure 76

Cost Vs. Span Length (3-Storey Building)

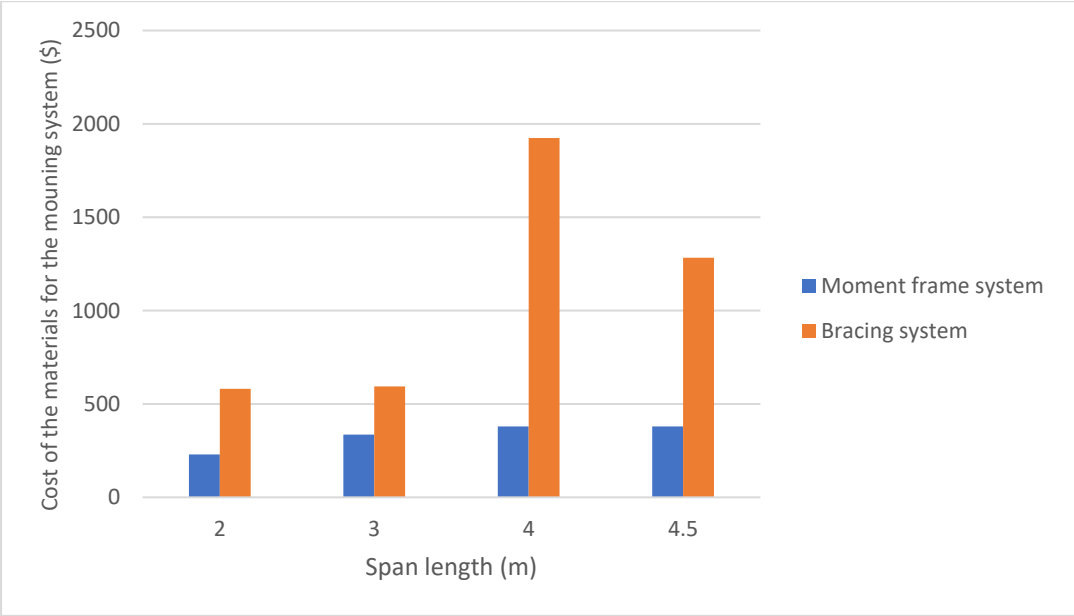
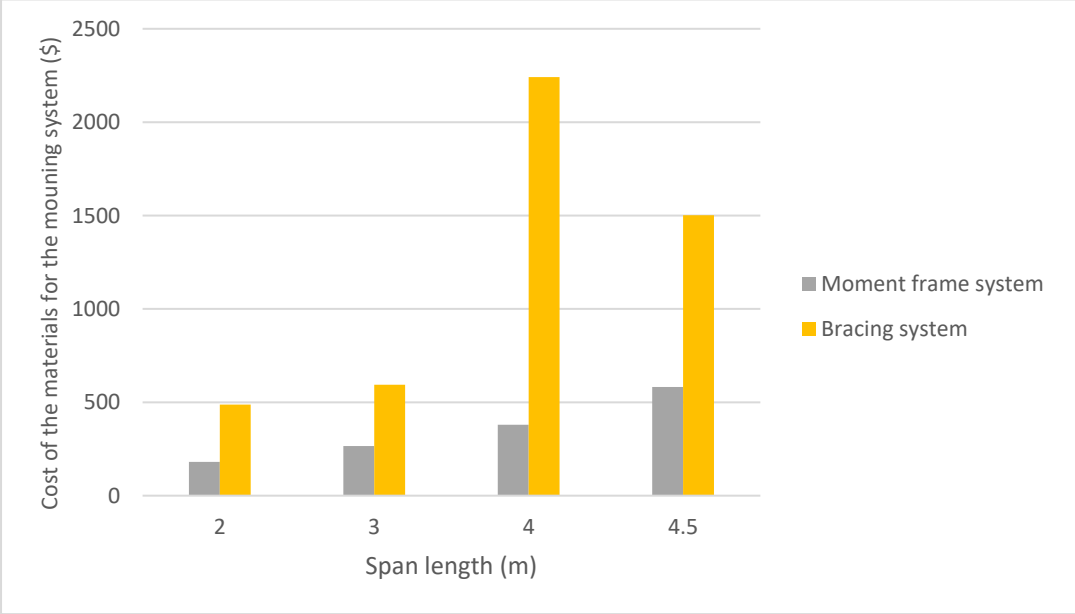


Figure 77

Cost Vs. Span Length (7-Storey Building)



According to the above figures, the following results can be found:

- When all the parameters are constant, designing the mounting system using the moment frame system is more cost-effective than using the bracing system.

- Increasing the span length reduces the number of columns and the entire length of the material, but due to controlling the deflection of the mounting system, the section size increases, which results in increasing the cost of the material.
- Models with a span length of 4 meters have 1-meter overhanging beams on each side of the mounting system. The deflection in these overhanging beams is controlled by increasing the section size and as a result, models with a span length of 4.5 meters have the same number of columns as models with a span length of 4 meters and 1-meter overhanging beams on each side, but since there are no overhanging beams, mounting systems can be designed using smaller sections. When the required length of the steel profiles is constant, using smaller sections is more cost-effective. Therefore, mounting systems with a span length of 4.5 meters are more cost-effective than mounting systems with a span length of 4 meters and 1- meter overhanging beams on each side.

✓ **Aesthetics**

PV panel mounting systems are usually installed on the roofs of buildings that have already been constructed and therefore they are usually inconsistent with the architecture of the building, destroying the harmony of the façade, and affecting the aesthetics of the surrounding area. Therefore, it is important to pay attention to the aesthetics of the building after installing rooftop PV panels. Some factors must be considered to minimize the negative impact of rooftop PV panels on the aesthetics of the building and its surroundings.

First, minimize the visibility of the mounting system by placing 1 meter between the mounting system and the edge of the roof

Second, control the height of the mounting system and avoid using tall mounting systems.

Third, minimize the number of columns and structural elements that result in reducing visual pollution.

In this study, a distance of 1 meter between the mounting system and the edge of the roof is considered. On the other hand, the height of mounting systems is 1.1 meters, which is the highest allowable height of rooftop mounting systems according to Nicosia standards for rooftop PV panels.

It should be noted that mounting systems designed by using moment frame systems are preferred, because there is no bracing in moment frame systems and the number of elements and visual pollution reduces, on the other hand, reducing the number of columns is desirable.

Thus, in both Type I and Type II residential buildings, it is preferable to use a moment frame system and reduce the number of columns from an aesthetic point of view, while a distance of 1 meter between the mounting system and the edge of the roof and the allowable height of the mounting system is considered.

Results and Discussion of the Case Study

The mounting system of the case study was inspected twice, a number of photographs of the structure were taken, the dimensions of the structural elements were measured, and some questions were asked of the residents. Then the mounting system was modelled with ETABS 2015, its status was checked, and structural problems were identified and listed. Finally, suitable alternative mounting systems were provided based on the building conditions.

During the inspection of this mounting system, modelling th mounting system with the software, and taking into account the existing standards for the mounting system of rooftop PV panels, the following problems were identified:

- ✓ Rusting problems
- ✓ Height of the structure
- ✓ Distance to the edge
- ✓ Connection problems
- ✓ Aesthetics
- ✓ Angle of installation
- ✓ Arrangement of panels
- ✓ Designing problems

These problems are discussed in the following.

- **Rusting problems**

According to the Northern Cyprus Solar Power Generation Plant Technical Specification, which in Turkish is called "Kuzey Kibris Güneş Enerjisi Üretim Santrali Teknik Şartnamesi", a mounting system of PV panels should last more than 25 years. On the other hand, the standard states that all elements of a mounting system must be made of galvanized steel. Although the mounting system was installed in early 2020, many elements of the structure have rusted so far. Rusting of the elements in this short period can be due to the climate of the region and the lack of galvanization of elements, which will cause several problems in the future.

Figure 78

Rusting Problem of the Mounting System Elements

- **Height of the mounting system**

The height of the PV panel mounting system is significant because it affects the beauty of the building and its surroundings. In addition, as the height of the mounting system increases, the effects of wind load increase, and as a result, stronger structural elements and larger sections must be used to withstand loads, which

ultimately increases the weight of the mounting system. As a result, most relevant standards have limited the height of rooftop PV panel mounting systems. The Nicosia standard, which governs PV panel mounting systems on the roof, limits the height of rooftop PV panel mounting systems to 1.1 meters. As shown in the photo, the height of the highest part of this mounting system is 3.9 meters.

Figure 79

The Height of the Mounting System

- **Distance to the edge**

The distance between rooftop PV panels and the edge of the roof is significant for several reasons. First, the distance affects the appearance of buildings and the

aesthetics of urban areas. Second, the distance between the edge of the roof and the panels provides convenient access to maintain and clean PV panels. Third, the proper distance between the edge of the roof and the mounting system in case of danger can be effective in accessing all over the roof. As a result, most standards specify a distance of 1 meter between the edge of the roof and rooftop PV panels. As shown in (Figure 80), the distance between the structure and the edge of the roof is less than 1 meter.

Figure 80

Distance Between the Mounting System and the Edge of the Roof

- **Connection problems**

Designing applicable and appropriate connections between structural members is critical given the size of the members, and efforts should be made to prevent a large number of members from connecting at one point to avoid complex connections and ultimately facilitate the construction of the structure.

As shown in (Figure 81), the 7 members of the mounting system are connected at one point. Considering such a connection in designing the mounting system of PV

panels is inappropriate and on the other hand, the way this connection is executed is extremely improper.

Figure 81

The Connection Between 7 Members of the Mounting System

- **Aesthetics**

Preserving the beauty of the building and paying attention to the aesthetics of the surroundings should be considered in the designing of the mounting system of rooftop PV panels. However, in many cases, the effects of these panels on the aesthetic of the building and the area have not been considered. This mounting system has damaged the beauty of the area due to its high height, lack of acceptable distance between the edge of the roof and the mounting system, and improper arrangement of the panels. It should be noted that the installation of water tanks and solar water heaters must follow certain rules because they play a role in the aesthetic of buildings, but this issue is beyond the scope of this research.

Figure 82

Effects of the Mounting system on the Aesthetics of the Building and Surroundings

- **The tilt angle of PV panels**

Installing panels with optimal tilt angles improves the efficiency of PV panels and installing panels with inappropriate tilt angles reduces their workability and power generation. According to YEK reports, the appropriate range of tilt angle for installing PV panels in this area is 25 to 35 degrees, while the installation angle of the panels in this structure is approximately 18 degrees according to the measurements. Due to the roof conditions, it is possible to install the panels at the optimal angle.

Figure 83

Tilt Angle of the PV Panels

- **Arrangement of the PV panels**

The arrangement of the panels affects the beauty of the structure and the symmetrical layout of the panels has a major effect on the appearance of a mounting system. Therefore, if possible, even roof furniture such as antennas and chimneys should be moved to allow symmetrical installation of rooftop PV panels. A more suitable layout could be considered for the panels in the case study mounting system.

Figure 84

The Layout of the Case Study PV Panel Mounting System

Stress Analysis of the mounting system with ETABS 2015

The mounting system is subject to different loads and 37 load combinations are defined in the software for the structural analysis based on ASCE 7-16. According to the analysis of the mounting system, some members have slenderness problems and some have deflection problems. (Table 15) and (Table 16) show the members that have slenderness problems and deflection problems.

Table 15

Slenderness Problem of the Structural Elements

Number	Member's type	Length (cm)	K	r (cm)	KL/r	Slenderness limitation	Slenderness condition
D1	Inclined member	574.3	1	1.9	302.3	200	Not OK
D4	Inclined member	407.2	1	1.9	214.3	200	Not OK
D5	Inclined member	407.8	1	1.9	214.6	200	Not OK
D2	Inclined member	574.9	1	1.9	302.6	200	Not OK

Table 16

Deflection Problem of the Structural Members

Number	Member's type	Length (cm)	Location of the maximum deflection (cm)	Deflection (cm)	Allowable Deflection (cm)	Deflection condition
B45	Inclined Member	384.1	193	1.91	1.07	Not OK
B36	Inclined Member	384.1	193	1.91	1.07	Not OK
B39	Beam	351	148	1.25	0.98	Not OK

Weight analysis of the mounting system

To determine the weight of the mounting system, first, the volume of the materials is calculated, and then the unit weight of steel is used to calculate the total weight of the mounting system.

The section of the steel profile used for all elements is SHS 50X50-2.6 and the total length of the material is 127.7 meters (22 steel profiles). According to the unit weight of steel, which is equal to 7850 kg/m³, the total weight of the mounting system is calculated as follows:

- ✓ Profile cross-section area: $493\ mm^2$
- ✓ The total volume of steel material: $0.063\ m^3$
- ✓ Total weight of the mounting system: $494.55\ kg$

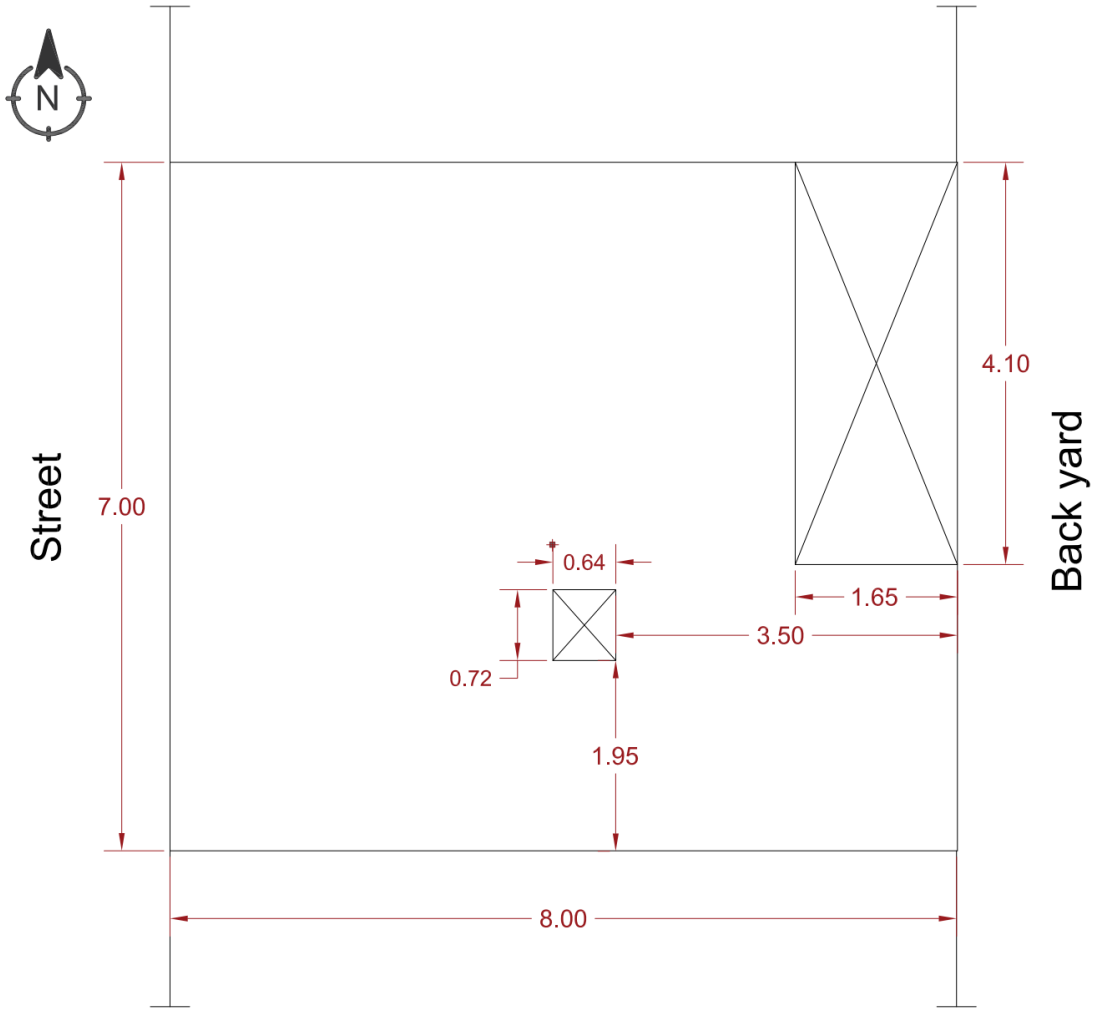
Alternative Mounting Systems for the Case Study

As previously explained, the mounting system of PV panels has many weaknesses and problems, therefore, alternative mounting systems for installing PV panels on the roof of the desired building are provided by taking into account the building conditions and the available roof area without moving the chimney, water tank, and solar water heater. The standards of mounting systems such as the allowable height of the mounting system, the required distance between the mounting system and the edge of the roof, the proper tilt angle of the panels, preventing shadows of the panels on each other, and the symmetrical arrangement of the panels are considered.

The available area on the roof for the installation of PV panels and the arrangement of roof furniture such as the chimney, water tank, and solar water heaters is shown in (Figure 85).

Figure 85

Roof Plan of The Case Study



Alternatives to the mounting system have been developed taking into account the results of previous sections of the investigation.

According to previous findings, the Type A column arrangement supports beams better than Type B, reducing the deflection of the beams and ultimately the size of the beam sections resulting in reducing the weight and the cost of the mounting system. On the other hand, the moment frame system causes less deflection, reduces the size of the sections and the weight of the mounting system, and reduces the budget required for the steel sections of the mounting system.

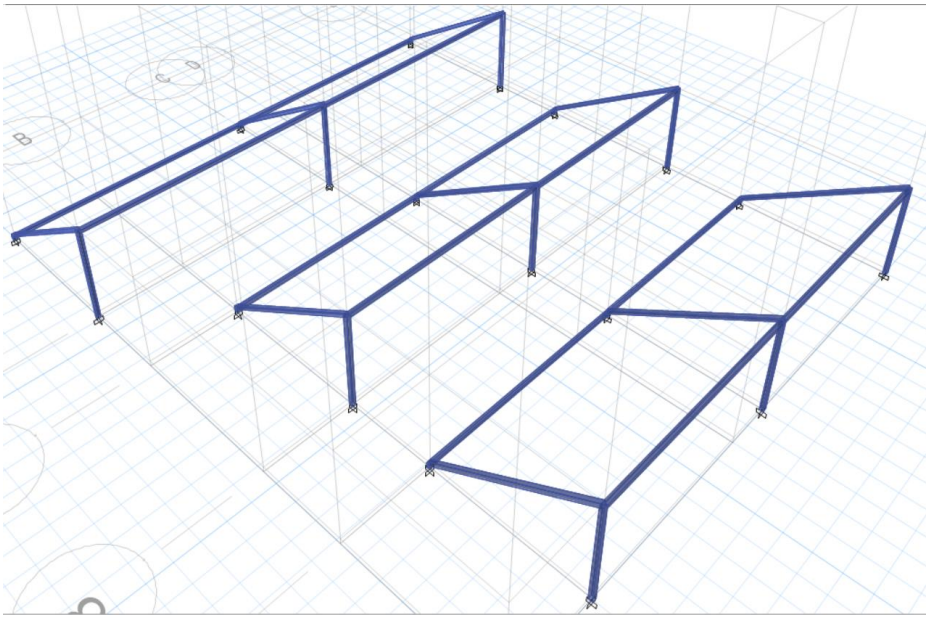
Alternative mounting systems hold 16 PV panels in 3 arrays. The length of one array of the mounting system is 6 meters and the other two arrays are 5 meters long. Details and explanations of the alternative mounting systems, cost analysis, and weight analysis are as follows.

The first alternative mounting system

In this alternative mounting system, the span length is 3 meters for the 6-meter array and 2.5 meters for the 5-meter arrays. The mounting system and arrangement of arrays are shown in (Figure 86).

Figure 86

The First Alternative Mounting System



(Table 17) shows the details of the alternative mounting system and its design results.

Table 17

Details of the First Alternative Mounting System

Criteria	**Details**
Number of installed panels	16 Panels
Height of the mounting system	1.1 meters
Distance from the edge of the roof	1 meter
Distance between the arrays	95 cm
Tilt angle	31 °
Material used	ST37-2
Profile section	SHS 40X40-3
Total steel length	59.9 m

The cost analysis and the weight analysis of the mounting system are provided below:

Table 18

Cost Analysis of the Mounting System

Criteria	**Details**
Profile section	SHS 40X40-3
Total length (m)	59.9
Number of profiles	10
Cost of each profile ($)	31.59
The total cost of mounting system material ($)	315.9

Table 19

Weight Analysis of the Mounting System

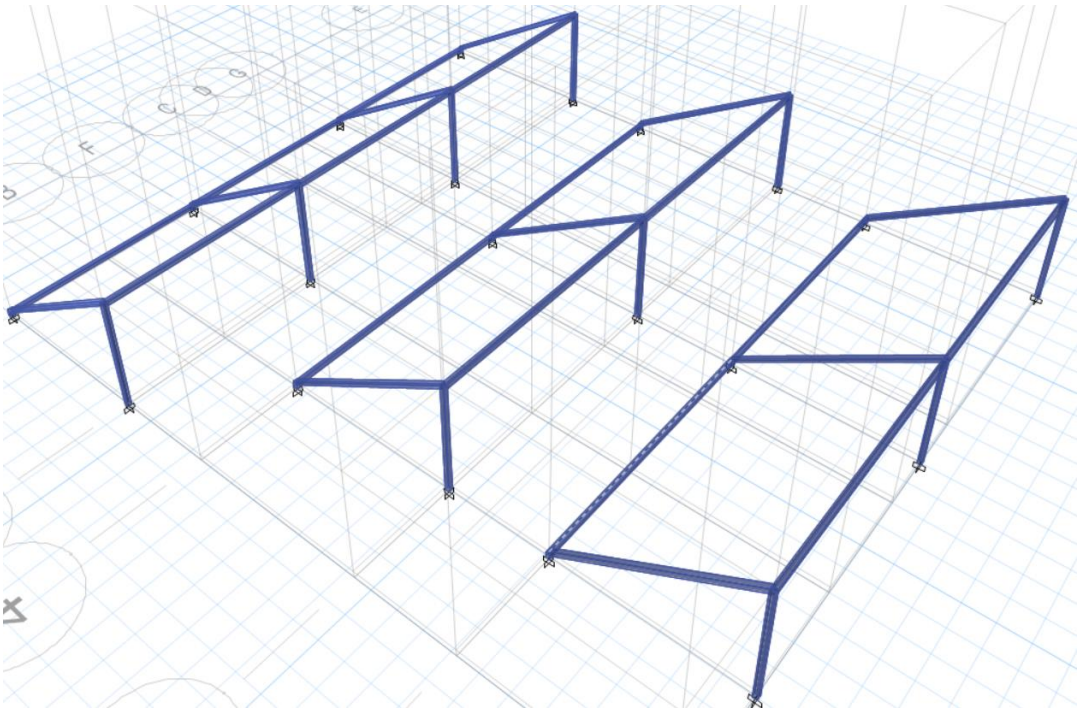
Criteria	**Details**
Profile section	SHS 40X40-3
Cross-section area of steel frame (cm^2)	4.44
Total length (m)	59.9
Total volume (m^3)	0.027
Unit weight of the material (kg/m^3)	7850
Total Weight of the mounting system(kg)	212
Number of panels	16
Weight of each panel (kg)	35
Total weight of PV panels and mounting system (kg)	772

The second alternative mounting system

In this alternative mounting system, the span length is 2 meters for the 6-meter array and 2.5 meters for the 5-meter arrays. The mounting system and arrangement of arrays are shown in (Figure 87)

Figure 87

The Second Alternative Mounting System



(Table 20) shows the details of the alternative mounting system and its design results.

Table 20

Details of the Second Alternative Mounting System

Criteria	**Details**
Number of installed panels	16 Panels
Height of the mounting system	1.1 meters
Distance from the edge of the roof	1 meter
Distance between the arrays	95 cm
Tilt angle	31 °
Material used	ST37-2
Profile section	SHS 40X40-2
Total steel length	63 m

The cost analysis and the weight analysis of the mounting system are provided in (Table 21) and (Table 22).

Table 21

Cost Analysis of the Mounting System

Criteria	**Details**
Profile section	SHS 40X40-2
Total length (m)	63
Number of profiles	11
Cost of each profile ($)	21.19
The total cost of mounting system material ($)	233.09

Table 22

Weight Analysis of the Mounting System

Criteria	**Details**
Profile section	SHS 40X40-2
Cross-section area of steel frame (cm^2)	3.04
Total length (m)	63
Total volume (m^3)	0.019
Unit weight of the material (kg/m^3)	7850
Total Weight of the mounting system(kg)	150
Number of panels	16
Weight of each panel (kg)	35
Total weight of PV panels and mounting system (kg)	710

As a result of weight analysis and cost analysis of alternative mounting systems, the second model offers a lighter and cheaper mounting system, which is 57% lighter than the current mounting system. On the other hand, it should be noted that due to the distance of 1 meter from the edges of the structure and also limiting the height of the installation system, alternative mounting systems have less impact on the aesthetics of the structure and cause less visual pollution.

It should be considered that 16 panels have been installed on the roof of this building and also alternative mounting systems have been designed to carry 16 panels, but the current mounting system lacks the required safety and efficiency due to poor design and execution. If alternative mounting systems are used, these PV panels and the roof space of the building can be used more effectively.

Review of Standards

The standard for installing rooftop PV panels in Nicosia, Northern Cyprus has been established on July 1, 2021, and it has various flaws, many cases have not been considered, and on the other hand, some parts of the standard are incomprehensible and vague. In the following, Nicosia's standards for installing PV panels on flat roofs are reviewed:

Standards for installing PV panels on flat roofs in Nicosia

The standard for the installation of PV panels in Nicosia was developed on July 1, 2021, and it has various flaws, many cases have not been considered, and on the other hand, some parts of the standard are incomprehensible and vague.

Three criteria are included in the section of the standard that deals with the installation of PV panels on flat rooftops. The criteria are:

- The highest part of the solar panels should not exceed 1.20 meters measured from the roof's level. (Chimneys and stair towers are not considered)
- Solar panels should be installed at least 1.00 meters away from the outer edge of the roof.
- To the extent practicable, solar panels should be installed in such a way as to minimize the impact on the exterior of the building.

For the original standard for the installation of PV panels in Nicosia see Appendix C.

Standards for installing PV panels on flat roofs from Other Countries

As mentioned in Chapter 3, 8 standards on the rooftop PV panels from some countries of the world are chosen to review and check the points.

(Table 23) shows the areas related to PV panels and mounting systems which are considered and governed by each standard.

Table 23

Standards Review

Parameters		PV panels						Roof				
Name	Country /region	Tilt angle	Orientation	Framing	Size	Panel layout	Color and contrast	Roof positioning	Roof area	Penetration	Accessibility	Roof material
Ensuring place-responsive design for solar photovoltaics on buildings: A good practice guide for designers, manufacturers, and installers	UK	X	X	X	X	X	X	X	X		X	
Photovoltaics in buildings	France	X	X	X	X	X	X	X	X	X	X	
Solar ready guidelines	Canada	X	X		X				X	X	X	
Standards and Requirements for Solar Equipment, Installation, and Licensing and Certification (A Guide for States and Municipalities)	USA		X	X	X			X	X	X	X	X
Solar Ready Building Design Guidelines for the Twin Cities, Minnesota	USA (Minnesota)	X	X	X	X			X	X	X	X	X
Handbook for rooftop solar development in Asia	Asia Development Bank	X	X	X	X	X		X		X	X	X
Photovoltaic Ready Guidelines	Canada	X	X		X	X		X	X	X	X	X

Table 23

Standards Review (Continue)

Parameters		Arrays		Mounting system					
Name	Country /region	Spacing	Shadow	Height	Edge distance	Material	Wind load	Gravity loads	Landscape
Ensuring place-responsive design for solar photovoltaics on buildings: A good practice guide for designers, manufacturers, and installers	UK		X	X	X	X	X	X	X
Photovoltaics in buildings	France	X	X			X			
Solar ready guidelines	Canada	X	X	X	X	X	X	X	
Standards and Requirements for Solar Equipment, Installation, and Licensing and Certification (A Guide for States and Municipalities)	USA	X	X	X	X	X	X	X	X
Solar Ready Building Design Guidelines for the Twin Cities, Minnesota	USA (Minnesota)	X	X	X	X		X	X	X
Handbook for rooftop solar development in Asia	Asia Development Bank	X	X	X		X	X	X	X
Photovoltaic Ready Guidelines	Canada	X	X	X	X		X	X	

As shown in (Table 23), various parameters are considered and different details are provided for rooftop PV panel mounting systems to ensure system longevity and optimal performance, maintain the safety of systems and residents, prevent financial losses, maintain the aesthetics of the building, and coordinate PV panels with urban architecture.

However, the standard of rooftop PV panels in Nicosia, Northern Cyprus is not accurate and in many cases is vague and unclear, so it can lead to misunderstandings, and thus users and solar panel installation companies act in different ways. As a result, creating standards with the use of clear and straightforward expression is crucial for appropriately conveying the concept.

In addition, the standard for the installation of PV panels in Nicosia, Northern Cyprus was developed on July 1, 2021, but this standard does not consider any improvement for the PV panels that had been installed before providing this standard, while many rooftop mounting systems were built with a low level of serviceability, high risk of failure in many cases, and considerable effect on the aesthetics of the building before developing this standard.

CHAPTER V
Conclusions and Recommendations

Given the advancement of technology and the reliance of modern life on energy in today's globe, the importance of a sustainable energy supply is not hidden from anyone. On the other hand, environmental crises are becoming more prevalent by the day and need to be addressed and fundamental actions carried out. One of the most debated issues ever is the use of clean and renewable energy sources such as solar energy.

Although generating electricity from renewable energy sources has fewer negative environmental consequences, considerations must be made to ensure system efficiency and optimal performance, maintain the system and individual safety, prevent financial losses, and limit the side effects.

When PV panels are installed on the roof of buildings, the roof and mounting system must withstand additional dead loads due to the weight of the PV panels and the mounting system, as well as wind loads. Wind loads on rooftop PV panels were calculated based on two different standards in this study which were TS498 and ASCE 7-16. The results show that since ASCE 7-16 specifically provides wind loads on PV panels, especially rooftop-mounted PV panels, the considered variables are accurate and the loads calculated according to this standard seem more reliable. Based on the results of ASCE 7-16 wind load calculations, uplift wind loads on PV panel mounting systems are 50% greater than downward wind loads, which have remarkable effects on the design of rooftop mounting systems.

Throughout this research, 32 ETABS models of mounting systems for holding rooftop PV panels were developed for installation on the roof of 3-storey buildings and 7- storey buildings, which were used to investigate the effects of factors including beam span length, load resisting system, and column arrangement on the deflection of the mounting system beams. The findings of these models were then utilized to develop another 32 ETABS models for holding PV panels for installation on the roofs of residential buildings by considering variables such as available roof area, required distance between arrays, the orientation of the building to the north, beam span length, and load resisting system. The effects of all parameters on the deflection of the beams

of the mounting system, the cost and weight of the mounting systems, and the aesthetics of the building have been studied, evaluated, and compared.

According to the findings of this study:

- Mounting systems designed with a moment frame system outperform those developed with a brace system in terms of beam deflection, size of steel frame sections, weight and cost of the complete mounting system, and aesthetics,
- Placing columns in the corner of the mounting system (Type I of column arrangement) provides better support for the beams, which reduces the deflection of the beams.
- Avoiding overhanging beams leads to a reduction in deflection of the beams and the steel frame sections, cost, and structure weight of the mounting system.
- Beam span length should be proportional to the weight and cost of the structure. In fact, although the number of columns decreases with increasing beam span lengths, a larger steel frame section is required to control the deflection of the beams, which eventually leads to an increase in the cost and weight of the mounting system. In other words, increasing the span length of the beams and reducing the number of columns reduce the length of the desired material, but require larger steel frame sections, which results in heavier and costlier mounting systems.
- The appearance of mounting systems, particularly those installed in urban areas and on building roofs, is critical. As a result, special considerations must be made in order to maintain and ensure the aesthetics of buildings and their surroundings, and minimalize the negative effects on the landscape.

The case study of this investigation is a rooftop PV panel mounting system in Nicosia, Northern Cyprus which was installed to carry 16 PV panels in early 2020. The current rooftop PV panel mounting system was examined and modelled using ETABS 2015, problems were identified, and two alternative mounting systems were proposed, while the relevant structural and architectural standards were met and the efficiency of the panels was maximized by considering the optimum tilt angle for PV panel installation and the minimum required distance between arrays. Besides, cost analysis and weight estimation were carried out for the alternative mounting systems.

The results show that by taking into account the architectural and structural standards, a lighter, cheaper, and safer mounting system can be installed with the same number of panels already installed, while the efficiency of the PV panels is increased due to the proper installation angle, in addition, the weight of the optimal alternative mounting system is about 70% less than the current mounting system.

Inspection of various rooftop PV panels in Nicosia, Northern Cyprus, revealed that the mounting systems have numerous structural and architectural problems. With the advancement of technology, one approach to solving current challenges is to adopt new standards and implement regulations to maintain system efficiency and optimal functioning while protecting the safety of systems and individuals.

As a result, certain countries have set distinct standards and guidelines for the installation of PV panels. Some of these standards have been reviewed, and proposals for improving the standards of rooftop PV panel mounting systems in Northern Cyprus have been made.

- **Aesthetics**

The use of clear expression to guarantee that the notion is presented effectively and precisely is a key component of standards. For example, the Nicosia standard on rooftop PV panel mounting systems states that "to the extent practicable, solar panels should be installed in such a way to minimize the impact on the exterior of the building", which is ambiguous and poorly articulated. This can lead to misconceptions, and consumers and solar panel installers act in disparate ways. Therefore, different related items such as the harmony of the panels with urban architecture, symmetry in panel layout, consideration of the visual aspect of the building and the landscape, etc. should be explicitly described in the standard.

- **Loads**

Solar panels, especially those installed on the roof, are subjected to a variety of loads throughout their service life, just like any other structure. Loads should be precisely determined based on local conditions, and mounting systems must be designed based on these loads. Ignoring the loads on the mounting systems leads to improper design, which ultimately increases the risk of damage to the mounting systems and PV panels. Loads on the mounting systems and PV panels must be indicated in the relevant standard according to local conditions, but the type of loads

and the associated calculation methods are not specified in the standard developed for PV panel mounting systems in Nicosia, Northern Cyprus.

- **Materials**

According to the Northern Cyprus Solar Power Generation Plant Technical Specification, which in Turkish is called "Kuzey Kibris Güneş Enerjisi Üretim Santrali Teknik Şartnamesi", the mounting system of PV panels should last more than 25 years. On the other hand, the standard mandates that all components of the mounting system must be made of galvanized steel. Given the weather condition in this area and the mounting system's 25-year lifespan, it is vital to consider the material of the mounting system, and failing to do so will result in various problems in the future. This issue should be specified in the standard of PV panel mounting systems to force installation companies to use the proper materials for mounting systems.

- **Angle of installation**

It is worth noting that the installation of PV panels with optimal tilt angles improves the efficiency of the panels while neglecting to do so diminishes the workability of PV panels and electricity generation. The ideal slope angle for installing PV panels in this area is 31-32 degrees, and the inclusion of this criterion in the standard draws more attention to it and forces PV panel installation companies to install PV panels with the proper tilt angle.

- **Monitoring and inspection**

Consideration of proper inspection by the competent body ensures that the rules and standards are strictly followed. Determining the inspection circumstances and adequate organization in the standard can improve order, on the other hand, executing inspections raises the level of dedication to the standards.

- **Considering the conditions of PV panels that have already been installed**

The standard must take into account some enhancements to the mounting systems that have already been installed, in order to improve their safety and serviceability, reduce their side effects on other buildings and avoid potential problems among neighbours, reduce glare issues, and improve the aesthetics of the buildings. Governmental financial support may be required to change and improve the already built mounting systems.

Although the roof of a building is usually one of the best places to install PV panels because of its condition and the mentioned items improve the safety, serviceability, efficiency, and aesthetics of PV panels and rooftop mounting systems, it should be noted that the roof of a building is not proper to install PV panels on all buildings, for example, the area of the roof may not be efficient due to the arrangement of roof furniture such as chimneys and water tanks or there are shadows from structures around on the roof of the building, or the roof area is insufficient to install the required number of PV panels, therefore the other places can be considered for PV panel installation. Depending on the building conditions, the surrounding area, and the relevant standards, building-integrated PV panels can be a suitable alternative or additional option for using solar energy.

Although the generation of power by using PV panels minimizes the reliance on non-renewable resources and contributes to the production of clean energy, it should be highlighted that these actions are necessary but insufficient. House and building architecture, building materials, landscaping, daily lifestyles, and other factors can all have an impact on the quantity of electricity consumed and the requirement to generate electricity.

Optimizing energy consumption and supplying energy from clean sources are the fundamental actions that can reduce energy consumption and dependence on non-renewable resources that all units of society, including citizens, governmental organizations, and other authorities should strive to achieve.

Recommendations for Future Studies

In this research, wind loads are calculated based on two standards, TS498 and ASCE 7-16, and the results are compared. But modelling, analyzing, and designing of the mounting systems are conducted based on ASCE 7-16. In future studies, other loading standards can be used to model, analyze and design mounting systems and compared the results with the results of this study. In addition, other heights and other types of roofs can be considered for buildings.

Static analysis is used to design mounting systems in this study. For future works, mounting systems can be designed by conducting dynamic analysis, and the result can be compared to the findings of this study.

Roof installation systems are external structures on the roof of a building and have complications and problems. Some studies can be conducted on the possibility

of considering a wide and open area out of urban areas by governments, that is suitable for the installation of PV panels, and citizens can buy or rent a part of the land to install their solar panels and move the rooftop mounting systems out of urban areas. Studies can also be done on the possibility of governments allocating some funds.

In addition, conducting some feasibility studies for the use of floating PV panels in this country and considering the possibilities, advantages, and disadvantages of using floating PV panels is a novel field for future studies.

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APPENDICES

Appendix A

Wind Load Calculations

Calculation of wind load for a rooftop PV panel mounting system based on TS-498 (3-storey building)

- ✓ **Location:** Nicosia, Northern Cyprus
- ✓ **Roof type:** Flat roof
- ✓ **Building type:** Residential building
- ✓ **Number of storeys:** 3
- ✓ **Building height:** 9 meters
- ✓ **The optimal tilt angle of PV panels:** 32 °
- ✓ **Basic wind speed:** $130\frac{km}{h} = 36.11\frac{m}{s}$

The wind load is calculated by using the following formula:

$$W = C_p q$$

The q is obtained using the related table (See Chapter 3) by considering the height of the building from the ground.

$$\boldsymbol{q = 0.8\frac{kN}{m^2}}$$

The wind load has been calculated, by considering 2 different wind directions, -X and +X, as mentioned in Chapter 3.

The wind pressure in the +X direction:

$$W(+x) = -0.4q = -0.4 \times 0.8 = -0.32\frac{kN}{m^2} = \boldsymbol{-320\frac{N}{m^2}}$$

The wind load in the -X direction:

$$W(-x) = (1.2sin\alpha)q = 1.2 \times \sin 32° \times 0.8 = 0.51\frac{kN}{m^2} = \boldsymbol{510\frac{N}{m^2}}$$

According to the size of the panels, the distributed load on each purlin will be as follow for the +X direction:

$$\omega_{purlin} = -320\frac{N}{m^2} \times \frac{1.956\,m}{2} = \boldsymbol{-313\frac{N}{m}}$$

According to the size of the panels, the distributed load on each purlin will be as follow for the -X direction:

$$\omega_{purlin} = 510\frac{N}{m^2} \times \frac{1.956\,m}{2} = \boldsymbol{499\frac{N}{m}}$$

Calculation of wind load for a rooftop PV panel mounting system based on TS-498 (7-storey building)

- ✓ **Location:** Nicosia, Northern Cyprus
- ✓ **Roof type:** Flat roof
- ✓ **Building type:** Residential building
- ✓ **Number of storeys:** 7
- ✓ **Building height:** 21 meters
- ✓ The optimal tilt angle of PV panels: 32 °
- ✓ Basic wind speed: $130\frac{km}{h} = 36.11\frac{m}{s}$

The wind load is calculated by using the following formula:

$$W = C_p q$$

The q is obtained using the related table (See Chapter 3) by considering the height of the structure from the ground.

$$\boldsymbol{q = 1.1\frac{kN}{m^2}}$$

The wind load has been calculated, by considering 2 different wind directions, -X and +X, as mentioned in Chapter 3.

The wind load in the +X direction:

$$W(+x) = -0.4q = -0.4 \times 1.1 = -0.44\frac{kN}{m^2} = \boldsymbol{-440\frac{N}{m^2}}$$

The wind load in the -X direction:

$$W(-x) = (1.2sin\alpha)q = 1.2 \times \sin 32° \times 1.1 = 0.70\frac{kN}{m^2} = \boldsymbol{700\frac{N}{m^2}}$$

According to the size of the panels, the distributed load on each purlin will be as follow for the +X direction:

$$\omega_{purlin} = -440\frac{N}{m^2} \times \frac{1.956\,m}{2} = \boldsymbol{-430\frac{N}{m}}$$

According to the size of the panels the distributed load on each purlin will be as follow for the -X direction:

$$\omega_{purlin} = 700\frac{N}{m^2} \times \frac{1.956\,m}{2} = \boldsymbol{685\frac{N}{m}}$$

Calculation of wind load for a rooftop PV panel mounting system based on ASCE 7-16 (3-storey building)

- ✓ **Location:** Nicosia, Northern Cyprus
- ✓ **Roof type:** Flat roof
- ✓ **Building type:** Residential building
- ✓ **Number of storeys:** 3
- ✓ **Building height:** 9 meters

Step 1:

The risk category for a residential building is type II. Therefore, the risk category of the PV panel mounting system on the roof of a residential building is consumed as type II. (See Chapter 3)

Step 2:

Basic wind speed in Nicosia, Northern Cyprus: $130\frac{km}{h} = 36.11\frac{m}{s}$

Step 3:

Determination of wind directionality factor (K_d): (See Chapter 3)

$$\boldsymbol{K_d = 0.85}$$

Determination of the exposure category:

The explanation of exposure category B is:

"Urban and suburban areas, wooded areas, or other terrains with numerous, closely spaced obstructions that have the size of single-family dwellings or larger"

By considering the location of the study (Nicosia, Northern Cyprus), exposure category B seems to be the most compatible.

Determination of the topographic factor (K_{zt}): (See Chapter 3)

$$\boldsymbol{K_{zt} = 1}$$

Determination of the ground elevation factor (K_e):

Ground elevation above sea level for Nicosia is 220 meters and interpolation is allowed by the standard. Therefore: (See Chapter 3)

$$K_e = \frac{1 - 0.96}{0 - 305}X + 1$$

$$K_e = \frac{1 - 0.96}{0 - 305} \times 220 + 1 = \boldsymbol{0.97}$$

Step 4:

Determination of the velocity pressure exposure coefficient (K_z): (See Chapter 3)

$$\boldsymbol{K_z = 0.70}$$

Step 5:

Determination of velocity pressure (q_z): (See Chapter 3)

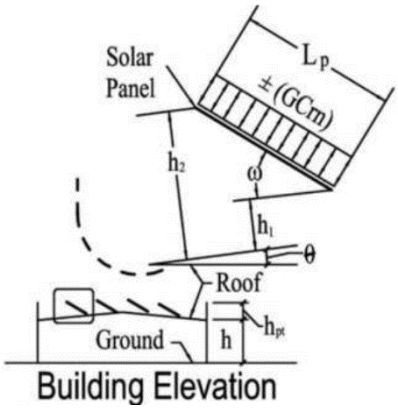
$$q_z = 0.613 K_z K_{zt} K_d K_e V^2 = 0.613 \times 0.7 \times 1 \times 0.85 \times 0.97 \times 36.11^2 = \boldsymbol{461.32\ N/m^2}$$

Step 6:

Determination of force coefficient.

The design wind load for rooftop PV panels can be calculated by the procedure explained in Chapter 3 if the structure confirms the following rules:

$L_p \leq 2.04\ m$
$\omega \leq 35°$
$h_1 \leq 0.61\ m$
$h_2 \leq 1.22\ m$



For the desired mounting system:

$L_p = 1.96\ m < 2.04\ m$ ✓
$\omega = 32° < 35°$ ✓
$h_1 = 0.06\ m < 0.61\ m$ ✓
$h_2 = 1.1\ m < 1.22\ m$ ✓

Therefore, the procedure explained in Chapter 3 can be used to calculate the wind load.

Mean roof height of a building:

$$h = 9\ m$$

Mean parapet height above the adjacent roof surface:

$$h_{pt} = 0.1\ \text{m}$$

Panel chord length for use with rooftop solar panels:

$$L_p = 1.96\ \text{m}$$

Determination of parapet height factor (γ_p)

$$\gamma_p = \min\left(1.2, 0.9 + \frac{h_{pt}}{h}\right) = \min\left(1.2, 0.9 + \frac{0.1}{9}\right) = \min(1.2, 0.91) = \boldsymbol{0.91}$$

Determination of panel chord factor (γ_c)

$$\gamma_c = \max\left(0.6 + 0.06L_p, 0.8\right) = \max(0.6 + 0.06 \times 1.956, 0.8) = \max(0.72, 0.8) = \mathbf{0.8}$$

Determination of array edge factor (γ_E) which is 1.5 for uplift wind loads and 1.00 for downward wind loads.

$\boldsymbol{\gamma_E}$	
Uplift wind loads	1.5
Downward wind loads	1.00

The effective wind area:

$$A = 1.96 \times max(\frac{1.96}{3}, 0.992) = 1.95\ m^2$$

Determination of normalized building length (m): (See Chapter 3)

$$L_b = \min(0.4(hW_L)^{0.5}, h, W_s) = \min(0.4(9 \times 20)^{0.5}, 9, 10) = 5.37m$$

Determination of normalized wind area: (See Chapter 3)

$$A_n = \frac{1000}{\left(max\ (L_b, 4.57)\right)^2} \times A = \frac{1000}{\left(max\ (5.37, 4.57)\right)^2} \times 1.95 = 67.6$$

Determination of nominal net pressure coefficient $(GC_{rn})_{nom}$ for rooftop solar panels: (See Chapter 3)

$$\boldsymbol{(GC_{rn})_{nom} = 1.8}$$

Determination of net pressure coefficient for rooftop PV panels (GC_{rn}) using the following formula:

$$(GC_{rn}) = \gamma_p \gamma_c \gamma_E (GC_{rn})_{nom}$$

$\boldsymbol{GC_{rn}}$	
Uplift wind load	$0{,}91 \times 0{,}8 \times 1{,}5 \times 1{,}8 = 1{,}97$
Downward wind load	$0{,}91 \times 0{,}8 \times 1 \times 1{,}8 = 1{,}31$

Step 7:

Determination of design wind load for rooftop PV panels. (See Chapter 3)

$$p = q_z(GC_{rn})$$

Wind load	
Uplift wind load	$\mathbf{461,32 \times 1,97 = 909 \frac{N}{m^2}}$
Downward wind load	$\mathbf{461,32 \times 1,31 = 605 \frac{N}{m^2}}$

According to the size of the panels, the distributed load on each purlin will be as follow:

Wind Load	
Uplift wind load	$\mathbf{909 \times \frac{1,956}{2} = 889 \frac{N}{m}}$
Downward wind load	$\mathbf{605 \times \frac{1,956}{2} = 592 \frac{N}{m}}$

Calculation of wind load for a rooftop PV panel mounting system based on ASCE 7-16 (7-storey building)

- ✓ **Location:** Nicosia, Northern Cyprus
- ✓ **Roof type:** Flat roof
- ✓ **Building type:** Residential building
- ✓ **Number of storeys:** 7
- ✓ **Building height:** 21 meters

Step 1:

The risk category for a residential building is type II. Therefore, the risk category of the PV panel mounting system on the roof of a residential building is consumed as type II. (See Chapter 3)

Step 2:

Basic wind speed in Nicosia, Northern Cyprus: $130\frac{km}{h} = 36.11\frac{m}{s}$

Step 3:

Determination of wind directionality factor (K_d): (See Chapter 3)

$$\boldsymbol{K_d = 0.85}$$

Determination of the exposure category:

The explanation of exposure category B is:

"Urban and suburban areas, wooded areas, or other terrains with numerous, closely spaced obstructions that have the size of single-family dwellings or larger"

By considering the location of the study (Nicosia, Northern Cyprus), exposure category B seems to be the most compatible.

Determination of the topographic factor (K_{zt}): (See Chapter 3)

$$\boldsymbol{K_{zt} = 1}$$

Determination of the ground elevation factor (K_e):

Ground elevation above sea level for Nicosia is 220 meters and interpolation is allowed by the standard. Therefore: (See Chapter 3)

$$K_e = \frac{1 - 0.96}{0 - 305}X + 1$$

$$K_e = \frac{1 - 0.96}{0 - 305} \times 220 + 1 = \boldsymbol{0.97}$$

Step 4:

Determination of the velocity pressure exposure coefficient (K_z): (See Chapter 3)

$$\boldsymbol{K_z = 0.89}$$

Step 5:

Determination of velocity pressure (q_z): (See Chapter 3)

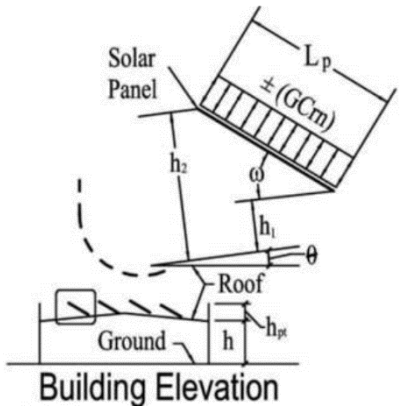
$$q_z = 0.613 K_z K_{zt} K_d K_e V^2 = 0.613 \times 0.89 \times 1 \times 0.85 \times 0.97 \times 36.11^2 = \mathbf{586.6\ N/m^2}$$

Step 6:

Determination of force coefficient.

The design wind load for rooftop PV panels can be calculated by the procedure explained in Chapter 3 if the structure confirms the following rules:

$L_p \leq 2.04\ m$
$\omega \leq 35°$
$h_1 \leq 0.61\ m$
$h_2 \leq 1.22\ m$



For the desired mounting system:

$L_p = 1.96\ m < 2.04\ m$ ✓
$\omega = 32° < 35°$ ✓
$h_1 = 0.06\ m < 0.61\ m$ ✓
$h_2 = 1.1\ m < 1.22\ m$ ✓

Therefore, the procedure explained in Chapter 3 can be used to calculate the wind load.

Mean roof height of a building:

$$h = 9\ m$$

Mean parapet height above the adjacent roof surface:

$$h_{pt} = 0.1\ \text{m}$$

Panel chord length for use with rooftop solar panels:

$$L_p = 1.96\ \text{m}$$

Determination of parapet height factor (γ_p)

$$\gamma_p = \min\left(1.2, 0.9 + \frac{h_{pt}}{h}\right) = \min\left(1.2, 0.9 + \frac{0.1}{21}\right) = \min(1.2, 0.905) = \mathbf{0.905}$$

Determination of panel chord factor (γ_c)

$$\gamma_c = \max\left(0.6 + 0.06L_p, 0.8\right) = \max(0.6 + 0.06 \times 1.956, 0.8) = \max(0.72, 0.8) = \mathbf{0.8}$$

Determination of array edge factor (γ_E) which is 1.5 for uplift wind loads and 1.00 for downward wind loads.

$\boldsymbol{\gamma_E}$	
Uplift wind loads	1.5
Downward wind loads	1.00

The effective wind area:

$$A = 1.96 \times max(\frac{1.96}{3}, 0.992) = 1.95\ m^2$$

Determination of normalized building length (m): (See Chapter 3)

$$L_b = \min(0.4(hW_L)^{0.5}, h, W_s) = \min(0.4(21 \times 20)^{0.5}, 9, 10) = 8.19\ m$$

Determination of normalized wind area: (See Chapter 3)

$$A_n = \frac{1000}{\left(max\ (L_b, 4.57)\right)^2} \times A = \frac{1000}{\left(max\ (8.19, 4.57)\right)^2} \times 1.95 = 29.1$$

Determination of nominal net pressure coefficient $(GC_{rn})_{nom}$ for rooftop solar panels: (See Chapter 3)

$$\boldsymbol{(GC_{rn})_{nom} = 2.35}$$

Determination of net pressure coefficient for rooftop PV panels (GC_{rn}) using the following formula:

$$(GC_{rn}) = \gamma_p \gamma_c \gamma_E (GC_{rn})_{nom}$$

$\boldsymbol{GC_{rn}}$	
Uplift wind load	$0{,}905 \times 0{,}8 \times 1{,}5 \times 2{,}35 = 2{,}55$
Downward wind load	$0{,}905 \times 0{,}8 \times 1 \times 2{,}35 = 1{,}7$

Step 7:

Determination of design wind pressure for rooftop PV panels (See Chapter 3)

$$p = q_z(GC_{rn})$$

Wind Load	
Uplift wind load	$586{,}6 \times 2{,}55 = 1496 \frac{N}{m^2}$
Downward wind load	$586{,}6 \times 1{,}7 = 997 \frac{N}{m^2}$

According to the size of the panels, the distributed load on each purlin will be as follow:

Wind Load	
Uplift wind load	$1496 \times \frac{1{,}956}{2} = 1463 \frac{N}{m}$
Downward wind load	$997 \times \frac{1{,}956}{2} = 976 \frac{N}{m}$

Wind loads based on ASCE 7-16 for other span lengths and effective wind areas are provided in (Table 14).

Appendix B

Seismic Load Calculations

Calculation of seismic load for a rooftop PV panel mounting system based on ASCE 7-16 (3-storey building)

- ✓ **Location:** Nicosia, Northern Cyprus
- ✓ **Roof type:** Flat roof
- ✓ **Building type:** Residential building
- ✓ **Number of storeys:** 3
- ✓ **Building height:** 9 meters
- ✓ **The optimal tilt angle of PV panels:** 32 °

Given the condition of the structure and procedure provided by ASCE 7-16 and reviewed in Chapter 3 of the thesis:

Determination of a_p according to the type of the structure and the related table (See Chapter 3):

$$\boldsymbol{a_p = 1}$$

Determination of importance factor (See Chapter 3):

$$\boldsymbol{I_p = 1}$$

Determination of R_p according to the type of the structure and the related table (See Chapter 3):

$$\boldsymbol{R_p = 2.5}$$

Height of the mounting system:

$$\boldsymbol{z = 1.1\ m}$$

The average roof height:

$$\boldsymbol{h = 9m}$$

Based on the standard, the value of $\frac{z}{h}$ need not exceed 1.

$$\frac{z}{h} = \frac{1.1}{9} = 0.122 < 1 \quad ✓$$

S_{DS} is calculated by the following formulas:

$$S_{DS} = \frac{2}{3} S_{MS}$$

$$S_{MS} = F_a S_s$$

S_s and F_a is as below for rooftop PV panels mounting system (See Chapter 3):

$$S_s = 0.75$$

$$F_a = 0.8$$

Therefore:

$$S_{MS} = F_a S_s = 0.8 \times 0.75 = 0.6$$

$$S_{DS} = \frac{2}{3} S_{MS} = \frac{2}{3} \times 0.6 = 0.4$$

Seismic loads for rooftop PV panel mounting systems are calculated white the following formula:

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\frac{R_p}{I_p}} (1 + 2\frac{z}{h})$$

$$F_p = \frac{0.4 \times 1 \times 0.4 \times W_p}{\frac{2.5}{1}} (1 + 2 \times 0.122) = \mathbf{0.08\ W_p}$$

F_p is not be considered as greater than:

$$F_p = 1.6\ S_{DS} I_p W_p = 1.6 \times 0.4 \times 1 \times W_P = 0.64\ W_p$$

F_p is not be considered as less than:

$$F_p = 0.3\ S_{DS} I_p W_p = 0.3 \times 0.4 \times 1 \times W_P = 0.12\ W_p$$

The seismic load is considered $0.12\ W_p$ for 3-storey buildings.

Calculation of seismic load for a rooftop PV panel mounting system based on ASCE 7-16 (7-storey building)

- ✓ **Location:** Nicosia, Northern Cyprus
- ✓ **Roof type:** Flat roof
- ✓ **Building type:** Residential building
- ✓ **Number of storeys:** 7
- ✓ **Building height:** 21 meters
- ✓ **The optimal tilt angle of PV panels:** 32 °

Determination of a_p according to the type of the structure and the related table (See Chapter 3):

$$\boldsymbol{a_p = 1}$$

Determination of importance factor (See Chapter 3):

$$\boldsymbol{I_p = 1}$$

Determination of R_p according to the type of the structure and the related table (See Chapter 3):

$$\boldsymbol{R_p = 2.5}$$

Height of the mounting system:

$$\boldsymbol{z = 1.1\ m}$$

The average roof height:

$$\boldsymbol{h = 21\ m}$$

Based on the standard, the value of $\frac{z}{h}$ need not exceed 1.

$$\frac{z}{h} = \frac{1.1}{21} = 0.052 < 1 \quad ✓$$

S_{DS} is calculated by following formulas:

$$S_{DS} = \frac{2}{3} S_{MS}$$

$$S_{MS} = F_a S_s$$

S_s and F_a is as below for rooftop PV panels mounting system (See Chapter 3):

$$S_s = 0.75$$

$$F_a = 0.8$$

Therefore:

$$S_{MS} = F_a S_s = 0.8 \times 0.75 = 0.6$$

$$S_{DS} = \frac{2}{3} S_{MS} = \frac{2}{3} \times 0.6 = 0.4$$

Seismic loads for rooftop PV panel mounting systems are calculated white the following formula:

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\frac{R_p}{I_p}} (1 + 2\frac{z}{h})$$

$$F_p = \frac{0.4 \times 1 \times 0.4 \times W_p}{\frac{2.5}{1}} (1 + 2 \times 0.052) = \mathbf{0.07\ W_p}$$

F_p is not required to be taken as greater than:

$$F_p = 1.6\ S_{DS} I_p W_p = 1.6 \times 0.4 \times 1 \times W_P = 0.64\ W_p$$

F_p shall not be taken as less than:

$$F_p = 0.3\ S_{DS} I_p W_p = 0.3 \times 0.4 \times 1 \times W_P = 0.12\ W_p$$

The seismic load is considered $0.12\ W_p$ for 7-storey buildings.

Appendix C

Turkish Standard for Mounting Systems pf PV Panels

The Municipality standard for installing PV panel in Nicosia, Northern Cyprus is as follows:

LEFKOŞA TÜRK BELEDİYESİ

YENİLENEBİLİR ENERJİ KAYNAKLARINDAN GÜNEŞ ENERJİ PANELLERİNİN KURULUMUNA YÖNELİK OLARAK LEFKOŞA BELEDİYE HUDUTLERI İÇERİSİNDE UYGULANACAK KURAL VE KOŞULLAR

BAŞVURU

Lefkoşa Belediyesi dahilinde monte edilecek olan güneş panellerinin, "Yenilenebilir Enerji Yasası" altında yapılan 1 Temmuz 2021 tarihli 146 sayılı resmi gazete. Yenilenebilir enerji (uygulama ve denetim) tüzüğü gereğince başvuru yapılması gerekmektedir.

Belediyeye yapılacak olan başvurularda aşağıda istenen belgelerin sunulması gerekmektedir.

- Güneş enerji panellerinin statik projesi.(Vizeli) 2 set
- Güneş enerji panellerinin elektrik projesi.(Vizeli) 2 set
- Güneş enerji panellerinin mimari projesi. (Bina ile birlikte – vizesiz) 2 set
- Mal sahibi İzni (Orijinal koçan ile koçan sahibinin başvurusu)
- Apartman ise; Tüm mal sahiplerinin imza ve koçanları ve vaziyet planında kurulum planı imzalanacak.
- 2 Adet orijinal yer planı.

SINIF I: BİNA ÇATISINDA GÜNEŞ ENERJİ PANELLERİ

Bina çatılarında elektrik üretimi amaçlı güneş enerji panellerinin kurulumu, eğimli ve düz çatılarda aşağıda belirtilen kural ve koşullara göre yapılacaktır.

Sınıf IA: ***Eğimli Çatılarda Güneş Enerji Panelleri***

- Güneş panellerinin çatıdan olan üst yüksekliği 20 santimetreden fazla Olmamalıdır. (yükseklik çatıya dik olarak ölçülür)
- Güneş panelleri, çatının en yüksek bölümünden daha yüksek olmamalıdır. (bacalar ve merdiven kuleleri çatı olarak kabul edilmez)
- Uygulanabilir olduğu ölçüde, güneş panelleri binanın dış görünümü üzerindeki etkiyi en aza indirecek şekilde kurulmalıdır.

Sınıf IB: ***Düz Çatılarda Güneş Enerji Panelleri***

- Güneş panellerinin en yüksek kısmı, çatı zemininden hesaplanmak üzere, 1.20 metreden daha yüksek olmamalıdır. (bacalar ve merdiven kuleleri çatı olarak kabul edilmez)
- Güneş panelleri çatının dış kenarından en az 1.00 metre uzakta yer almalıdır.

- Uygulanabilir olduğu ölçüde, güneş panelleri binanın dış görünümü üzerindeki etkiyi en aza indirecek şekilde kurulmalıdır.

SINIF II: BİNA CEPHELERİNDE GÜNEŞ PANELLERİ

- Bina cephelerine kurulacak olan güneş panelleri cephe kaplama şeklinde olmalıdır.
- Cephe aldığı duvardan uzaklığı 20 santimetreden fazla olmamalıdır. (yükseklik cepheye dik olarak ölçülür)
- Bina köşelerinden ve çatıdan en az 1.00 metre uzaklıkta kurulmalıdır.
- Bina cephesine kurulacak olan güneş panelleri, binanın estetik görüntüsünü etkilemeyecek şekilde kurulmalıdır.
- Pencere, kapı, balkon v.b açıklıklar güneş panelleri ile kapatılmamalıdır.

SINIF III: GARAJ, YARDIMCI BİNA, V.B BİNALARIN ÇATILARINDA GÜNEŞ PANELLERİ

Ana binaya yardımcı kullanımlar olarak inşa edilen müştemilatlar, ana binanın yer aldığı bahçede yer almaktadır. Güneş panellerinin bu binalara kurulmasındaki koşullar, Sınıf I'de belirtilen kural ve koşullara göre yapılmalıdır.

SINIF IV: BAHÇEDE KURULACAK GÜNEŞ PANELLERİ

Sınıf IVA: Pergola Şeklinde Kurulacak Güneş Panelleri

- Güneş panellerinin monte edileceği pergolalar arazi sınırından en az 3.00 metre geriye inşa edilecektir.
- Kurulumun hiçbir bölümü, bahçe zemininden ölçülmek üzere, zemin kat yüksekliğini ve her halükarda 4.00 metre yüksekliği aşmamalıdır.
- Pergola üzerine kurulacak olan güneş panelleri, çevresi ile uyumlu olacak şekilde kurulmalıdır.

Sınıf IVB: Bahçe İçerisine Kurulacak Güneş Panelleri

- Kurulum mülk sınırından en az 3.00 (üç) metre uzaklıkta olmalıdır.
- Kurulumun en yüksek noktası, bahçe zemininden ölçülmek üzere, 2.50 metreden yüksek olmamalıdır.
- Kurulum mülk sınırından 3.00 (üç) metre mesafe içerisine kurulacaksa, kurulumun hiçbir bölümü 1.20 (yüz yirmi santimetre) metre yüksekliği aşmamalıdır.
- Bahçe içerisine monte edilecek olan güneş panelleri, çevresi ile uyumlu olacak şekilde kurulmalıdır.

Appendix D

Ethical Certificate

03/06/2022

ETHICS LETTER

TO GRADUATE SCHOOL OF APPLIED SCIENCES

REFERENCE: SHAGHAYEGH OSTOVAR RAVARI (20194332)

The aforementioned candidate is one of the Master's students in the field of Civil Engineering. She is working on a thesis under our supervision, entitled "ASSESSMENT OF THE SOLAR PANEL MOUNTING SYSTEMS WITH ARCHITECTURAL AND ENGINEERING CONTEXT IN NICOSIA CITY AS A CASE STUDY". The work is based on modeling solar panel mounting systems and the application of the software. The data used in this study was collected from literature review, field inspections and observations. The data were then analyzed, the current state of PV panel mounting systems was evaluated based on data analysis, and the main weaknesses, major concerns, and critical problems were identified.

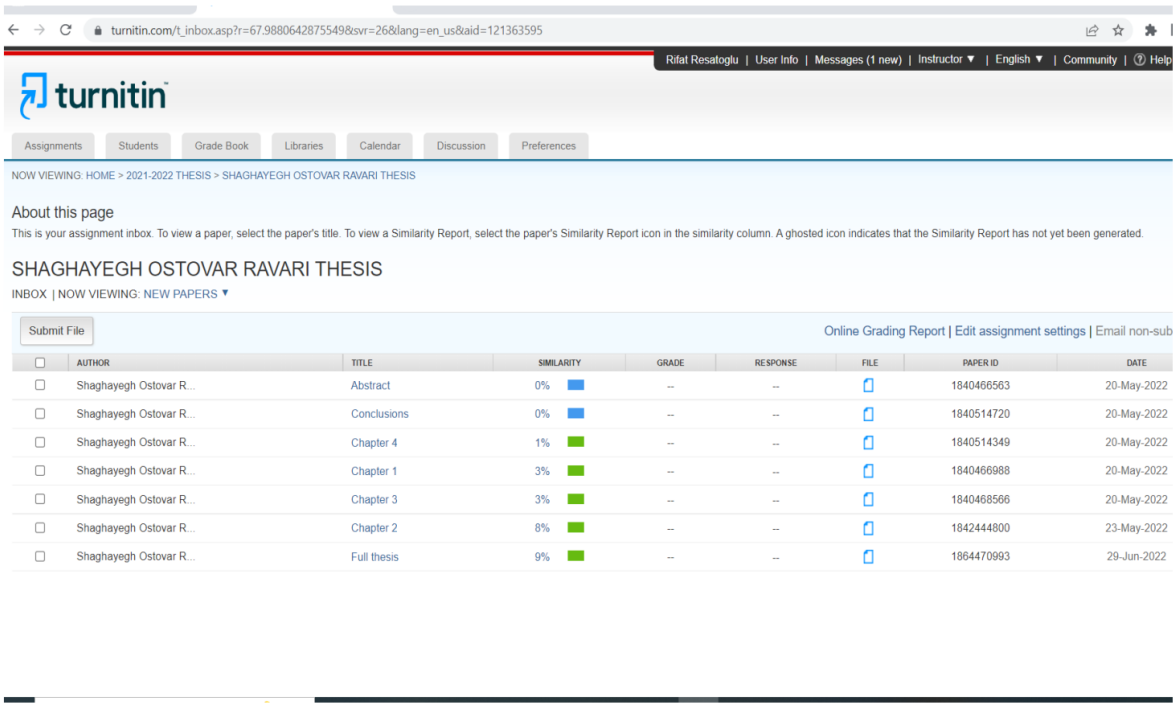
Sincerely yours,

Assoc. Prof. Dr. Rifat REŞATOĞLU
(Supervisor)
Civil Engineering Department,
Faculty of Civil and Environmental Engineering

Assist. Prof. Dr. Ayten ÖZSAVAŞ AKÇAY
(Co-Supervisor)
Architecture Department,
Faculty of Architecture

Appendix E

Similarity Check Report



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