A Research on Improving the Energy Performance of Residential Buildings

Aynur Kazaz and Ender Yetim

June 12, 2024

A Research on Improving the Energy Performance of Residential Buildings

A. Kazaz and E. Yetim
Akdeniz University, Civil Engineering Department, Antalya, Turkey
akazaz@akdeniz.edu.tr, ender-ytm@hotmail.com

Abstract

The research focuses on the improvement of lighting systems and the impact of photovoltaic applications on energy efficiency in buildings, aiming to increase building energy efficiency in response to global challenges such as population growth and urbanisation. The study, conducted in Antalya, located in the Mediterranean Climate Zone, evaluates the impact of upgrading the lighting system and integrating photovoltaic panels in three selected blocks within an island based settlements. Energy efficiency assessments cover a variety of factors such as building location, orientation and energy use scenarios including both natural gas and electricity for heating. Hourly analyses using DesignBuilder simulation and PVsyst software show that improving lighting leads to an average 6% reduction in energy consumption, while the implementation of photovoltaic systems leads to an additional 11% reduction. These findings underline the significant potential for reducing energy expenditure and environmental footprints. By demonstrating the effectiveness of an island-based strategy for improving building energy efficiency, this study extends the scope of energy saving initiatives from floors, spaces and buildings to an island-based approach.

Keywords: *building energy simulation, energy efficient design, energy efficiency, lighting system improvement, photovoltaic system design.*

Introduction

The rapid increase in the world population brings along the need for shelter. In order to meet this need, new settlement areas are opened, new buildings are constructed and cities are gradually growing. However, this rapid growth leads to an increase in energy demand. Scarce natural resources are consumed rapidly and unconsciously to meet this demand. This situation causes climate change and creates a global environmental disaster. As the demand for energy increases, energy costs also increase. This situation causes energy to become an important issue for countries.

Within the scope of the 2030 strategy, the European Union (EU) has set targets such as reducing greenhouse gas emissions by 40% compared to 1990 levels, increasing the share of renewable energy sources in energy consumption to at least 32% and achieving 32.5% energy savings (European Commission, 2014). In order to achieve these targets, according to the World Energy Outlook-2022 (WEO) Report of the International Energy Agency (IEA), 1.3

trillion dollars have been spent by the public and private sectors in the world for energy efficiency in buildings, industrial structures and transport. In addition, in order to reach the net zero emission target by 2050, the cost of clean energy investment in the world is projected to increase to approximately 4 trillion dollars by 2030 (IEA, 2022).

A similar situation is being experienced in Turkey in parallel with the population growth and urbanisation phenomenon in the world. According to the data of Turkish Statistical Institute (TÜİK) 2023; while the ratio of urban population to total population was 64.9% in 2000, this ratio reached 93% in 2023 (TÜİK, 2023). The fact that 81% of the energy used in dwellings in Turkey is used for heating purposes shows that dwellings in Turkey are insufficient in terms of energy efficiency. It has been revealed that Turkey's energy saving potential has reached 50% in buildings (Pamir, 2017).

In order to use energy efficiently in buildings, there are many studies on the energy efficiency of wall elements, opaque components formed by insulation materials and transparent components formed by glass and joinery (Vincelas and Ghislain, 2017; Kon, 2018; Alsayed and Tayeh, 2019; Aydin and Biyikoglu, 2020; Urbikain, 2020; Rosti et al., 2020; Mousavi Motlagh et al., 2021; Aktemur et al., 2021; Sayadi et al., 2022). In the literature, it has been observed that there are studies on building envelope design, which is generally one of the energy efficient building criteria, and energy efficiency calculations are made by considering the building heating load.

In this study; the effect of photovoltaic panel system application to selected base buildings as well as the improvement of the lighting system on energy performance in an island-based residential compound in Antalya, which is located in the Hot-Humid Climate Zone, is analysed. The most distinctive feature that distinguishes the study from other studies is that energy efficiency is not evaluated at the level of a building, floor or neighbourhood, but at the island-based settlement level. In addition, since the heating needs of the buildings in Antalya, which is located in the Mediterranean Climate Zone, are widely met with electrical energy, the analyses are repeated for the case where electrical energy is used as well as natural gas in heating within the scope of the study and energy efficiency is examined according to the type of fuel used in heating.

Improvement of Lighting System in Energy Efficient Residence Design

When the energy consumption of buildings is analysed, it is seen that electricity is mostly consumed by electrical equipment within the scope of mechanical systems. Daylight, motion and presence sensors and automatic time control in electrical systems provide savings in energy consumption. According to ASHRAE 90.1-2010 standard, if programmed time control is used in the lighting system, 10% and 15% of the electrical energy consumed for lighting is saved if presence sensors are used. Energy saving and effective use of energy can be achieved with a lighting that is suitable for the purpose, of high quality and provides good visual conditions without exceeding the required illuminance level in buildings (Yüksel, 2019).

Photovoltaic Panel System Application in Energy Efficient Residential Design

PV (photovoltaic) panels are systems that generate electrical energy from the sun to meet the electricity requirements of buildings for heating, cooling and lighting. These panels, which are used to convert solar energy into electrical energy, are one of the most important renewable energy technologies in energy efficient building design since they do not cause greenhouse gases during use. It has not become widespread in our country due to high initial investment costs and lack of necessary information studies (Kılıç Demircan and Gültekin 2015; Kılıç Demircan and Gültekin, 2017). Roof applications of PV panels are applied in two different ways as mounted and integrated PV systems. Building integrated PV systems replace the roof structure and form the shell itself (Ulusoy Şentürk and Altın, 2014), (Figure 1.).

Figure 1: PV panel roof applications; a) terrace roof PV systems, b) integrated PV systems, c) mounted PV systems (Daima Enerji, 2023).

Method

In the study, an island-based campus project in Antalya, which is located in the Mediterranean Climate Zone and classified in the 1st Degree Day Zone according to the Turkish Standards Institute (TS 825), with a hot-humid climate, was selected as a sample. The extent to which the energy need can be reduced by improving the lighting system in the buildings selected in the island-based campus and the extent to which the energy need can be met by photovoltaic panel application are examined separately.

Within the scope of the study; Block B, Block D and Block F were preferred as "Base Building" in order to examine the improvement of the lighting system and photovoltaic panel application by taking into account factors such as orientation, location, facade area, number of storeys, transparent surface ratio of the buildings in the island-based campus. Block B, Block D and Block F were modelled according to the current situation and "Base Building Models" were created. "Design Building Models" were created by taking into account the power densities recommended by the American Society of Heating, Refrigeration and Ventilation Engineers (ASHRAE) according to the spaces and using LED (Lighting Emited Diodes) bulbs instead of saving bulbs (compact fluorescent bulbs) only in the base buildings so that the lighting fixtures remain constant.

Energy cost, emission and saving ratios were obtained by comparing the energy consumption between the Base Building Models and Design Building Models. The analyses were performed by using meteorological database which is a dynamic thermal simulation programme and DesignBuilder dynamic simulation tools with 3D modelling capability. The cost of improving the lighting system in the Base Buildings was calculated and cost analysis was made. Cost information of saving and Led bulbs were obtained from the companies in the market.

There is no photovoltaic panel system to generate electricity from solar energy in the base buildings considered in the study. In the study, it is aimed to obtain electricity generation from solar energy by designing photovoltaic panels in base buildings. In this context, PV electricity generation report of the base buildings was obtained with the help of the PV simulation software provided by cw-energy company in order to design solar PV systems. PV system cost was obtained from the companies in the market. Cost analyses were made for each block and presented in tables.

Within the scope of the study, the analyses were repeated by using electric energy as well as natural gas as heating energy in the buildings. In the study, 2 Base Building models were created for each block according to the type of energy used in heating. In the case where natural gas is used as heating energy, the "Design Building-1" model was obtained by improving the lighting system and applying photovoltaic panel system to the "Base Building-1" (heating natural gas; cooling electricity) model. In the case where electric energy is used as heating energy, "Design Building-2" model was obtained by improving the lighting system and applying photovoltaic panel system to the "Base Building-2" (heating electricity; cooling electricity) model.

Findings

The study area has been selected as an island-based urban transformation project and consists of 6 blocks, 317 houses and a total construction area of 37.647 m^2. Block B consists of 10 floors and has 76 independent sections with a total net usage area of 4743,7 m^2. D block has 11 floors, 41 independent sections, with a total net usage area of 5102,4 m^2. Block F has 9 floors, 51 independent sections, total 5201,3 m^2 net usage area. Within the scope of the study; Block B, Block D and Block F were preferred as "Base Buildings" by considering factors such as orientation, location, façade area, number of storeys, transparent surface ratio of the buildings in the island-based campus. The island-based residential compound representing the energy consumption behaviour of the base buildings was modelled (Figure 2).

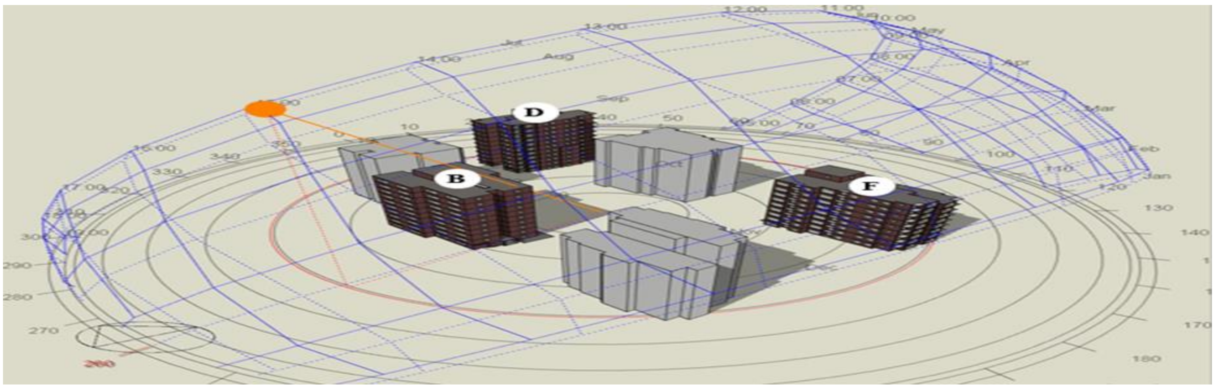

Figure 2: Island-based model image of the study area.

Heating and cooling load calculations for Antalya province where the Base Buildings are located, ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) recommended by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) according to ASHRAE 90.1-2010 standard ASHRAE Climate Zone 3A Region (Turkey's 1st Climate Zone) climate data were used. Heating in the buildings is done with boiler+radiator and split air conditioner (7800W, COP:3.20), cooling is done with split air conditioner (7100W, EER:3.00). In the calculations, the indoor air temperature comfort value is taken as 22°C for the heating period and 25°C for the cooling period. Natural ventilation is designed in the buildings and air exchange coefficient (ACH) is taken as 0.5(1/h). Base Buildings and Design Buildings are modelled according to ASHRAE Standard residential use profile. In this context, the number of people using the buildings is taken as 20 m^2/person and the operation hours/days are taken as continuous, 7/24.

Lighting System Improvement

Only the bulb type and lighting power density have been changed so that the electrical appliances used in the base buildings remain the same. Improvements were made in the lighting system in the base buildings by using 9W and 14W LED (Lighting Emited Diodes) bulbs, which have approximately equivalent luminous intensity (lumens) and more energy efficiency, instead of 12W and 20W saving bulbs (compact fluorescent bulbs). The electrical equipment power density value did not change since there was no electrical equipment change after the improvement. Electrical equipment power density was taken as 6 W/m^2 as in the Base Buildings. The light bulbs used in the lighting system before and after the retrofit and the values of the lighting power density in the buildings before and after the retrofit are shown in Table 1 and Table 2, respectively. Energy cost, emission and saving rates were obtained by performing hourly analyses between the existing building models (Base Building) and Design Building models with the Design Builder simulation programme. The annual energy consumption values of the Base Buildings and Design Buildings, energy saving rates and the increase in the cost of implementation are presented in Table 3.

Table 1. Lighting system improvement scenarios.

Design Scenario	Bulb Type	Application Areas						
		Parlour	Kitchen	Bedrooms	Antre	Bathroom 1	Bathroom 2	Balcony
Current Status	Tasarruflu	20W	20W	20W	20W	12W LED	12W	20W
Design Scenario	LED	14 W	14 W	14 W	14 W	12 W	9 W	14 W

Table 2. Values of building lighting power density before and after improvement.

Mahal	Base Buildings (W/m²)	Design Buildings (W/m²)
Apartment	12	7,8
Corridors/Common Areas	3,2	2,3
Mechanical Room	8	5,6

Table 3. Comparison of lighting costs of base buildings and design buildings.

Account Items	Base Building 1	Design Building 1	Base Building 2	Design Building 2
Block B				
Energy Consumption (kW)	351880,65	333499,09	311385,92	288870,39
Bulb Cost ($)	2195,74	3631,08	2195,74	3631,08
Energy Savings (kW)	5,22%		7,23%	
Cost Increase ($/m²)	0,30		0,30	
Block D				
Energy Consumption (kW)	325667,92	308548,74	275640,13	255948
Bulb Cost ($)	1183,80	1958,24	1183,80	1958,24
Energy Savings (kW)	5,26%		7,14%	
Cost Increase ($/m²)	0,15		0,15	
Block F				
Energy Consumption (kW)	343797,43	327085,15	301847,08	281223,79
Bulb Cost ($)	1469,97	2431,67	1469,97	2431,67
Energy Savings (kW)	4,86%		6,83%	
Cost Increase ($/m²)	0,18		0,18	

When Table 3 is analysed, it is seen that if LED bulbs are used instead of saving bulbs used in the Base Buildings, total energy savings ranging from 4.9% to 7.2% are provided in the buildings against the cost increase of approximately 18.9 $ per apartment.

Photovoltaic Panel Design and Application

In the study, it is aimed to obtain electricity generation from solar energy by designing photovoltaic panels in Base Buildings. For the terrace roof PV system applied to the Base Buildings, the optimum design was realised by considering the placement and orientation of the panels, the location where the system will be installed and the shading effect (Figure 3.).

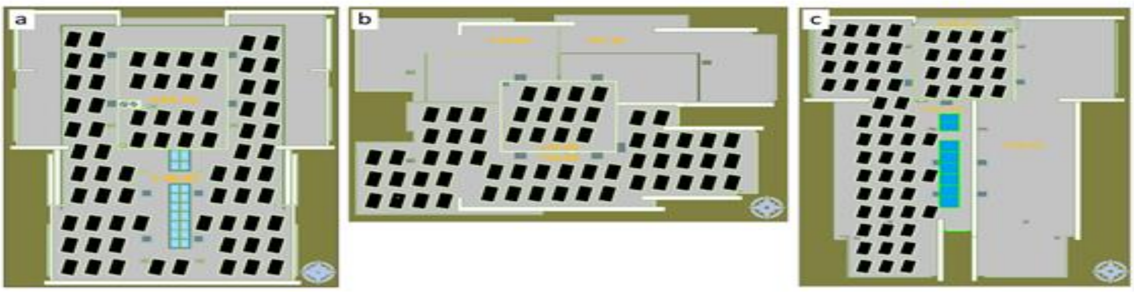

Figure 3: Photovoltaic panel application in base buildings; a) Block B base building, b) Block D base building, c) Block F base building.

The annual energy amount to be produced by the PV system was calculated with the PV simulation software offered by cw-energy company. The location of the building, meteorological data, all system components and system losses were defined as input to the Solar PV programme and 8760 hours of simulation was performed. As a result of the simulation, the amount of electricity generated in the Base Buildings is presented in Table 4.

Table 4. Photovoltaic panel system information applied to base buildings.

PV System Information	Unit	B Block Design Building	D Block Design Building	F Block Design Building
Power	kWp	25,4	18,9	20,4
Number of Panels	Quantity	74	60	64
Roof usage area	m^2	220	108	115
Amount of electricity produced with PV	kWh/year	38493,17	28565	30929
Installation cost	$	25553,90	18963,33	20532,82
Cost increase	$/m^2$	4,9	3,4	3,6
Savings from mains electricity	$/year	3312,17	2457,89	2661,30
System amortisation time	year	7,7	7,7	7,7

In B-D-F Design Building-1, where natural gas is used for heating and electrical energy is used for cooling, the ratio of meeting the annual energy consumption with the solar energy system is 14%, 12%, 11%, respectively. In B-D-F Design Building-2, where heating and cooling are met by using electrical energy, these values are 12%, 10%, 10%, respectively. It is seen that with the application of photovoltaic panel system in the blocks, an average of 249.922 Tn CO^2 emission can be prevented in each block. It is known that the lifetime of the photovoltaic panel system is 25 years. In this case, considering the depreciation periods of photovoltaic panel systems, it can be said that approximately 12% of the electricity used in the blocks for about 17 years with the solar energy system can be met almost free of charge every year.

Results

In this study, the effect of the improvement of the lighting system and the design of photovoltaic panels on the energy performance of the building in the buildings selected in the island-based campus in Antalya, located in the Mediterranean Climate Zone, is analysed. Analyses were made on the energy consumption data of heating, cooling, lighting and ventilation systems in the Design Building Models created after the improvement of the lighting system in the base buildings. As a result of the analyses, it was seen that annual energy savings between 32.5% and 33.0% were achieved in lighting-related energy consumption, and the total energy savings reached 7.2% depending on the type of fuel used. In case of integrating photovoltaic panels in the base buildings, it is seen that annual energy consumption can be met by solar energy between 10% and 14%. The cost of upgrading the lighting system and the cost of integrating photovoltaic panels were calculated to be 0.2 $/m^2$ and 4.0 $/m^2$, respectively.

The study is unique in that design parameters such as the location, position and distance between buildings are taken into consideration in island-based settlements. Another important feature of the study is that the heating needs of the buildings in Antalya are widely met with electrical energy, so the analyses in which electrical energy is used in addition to natural gas in heating are carried out within the scope of the study.

As a result, it is concluded that the bulbs to be preferred in the lighting system are an important parameter to be considered when the cost of improvement of the lighting system in the buildings selected in the island-based settlement in Antalya, which is located in the Mediterranean Climate Zone, and the energy saving rates obtained are considered. It has been observed that energy costs can be reduced as a result of the use of photovoltaic panel system in the houses located in the Mediterranean Climate Zone. In the study, it is thought that the results will contribute significantly to the academia and the construction sector and will be guiding since it is focused on sustainable energy and the energy-cost relationship with the improvement of the lighting system and the application of photovoltaic panel system.

References

Aktemur, C., Bılgın, F. and Tunçkol, S. (2021). Optimisation on the thermal insulation layer thickness in buildings with environmental analysis: an updated comprehensive study for Turkey's all provinces. *Journal of Thermal Engineering*, *7*(5), 1239-1256.

Alsayed, M. F., & Tayeh, R. A. (2019). Life cycle cost analysis for determining optimal insulation thickness in Palestinian buildings. *Journal of Building Engineering*, *22*, 101-112.

Aydin, N., & Biyikoglu, A. (2020). The effect of cooling load on optimum insulation thickness in residential buildings. *Isı Bilimi ve Teknigi Dergisi-Journal of Thermal Science and Technology*, *40*(2), 281-291.

Daima Enerji. (2024, March 31). *Fotovoltaik/Güneş enerjisinden elektrik üretimi*. https://www.daimaenerji.com/

Demir, H., ÇIRACI, G., Reyhan, K., & Ünver, Ü. (2020). Aydınlatmada enerji verimliliği: Yalova Üniversitesi Mühendislik Fakültesi durum değerlendirmesi. *Uludağ Üniversitesi Mühendislik Fakültesi Dergisi*, *25*(3), 1637-1652.

European Commission. (2022, April 4). *2030 climate & energy framework*. https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2030-climate-energy framework_en.

IEA 2022. (2023, March 5). *World Energy Outlook 2022*, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2022

Kılıç Demircan, R., & Gültekin, A. B. (2015). Binalarda pasif ve aktif güneş sistemlerinin incelenmesi. In *2nd International Sustainable Buildings Symposium sunulan bildiri, Gazi Üniversitesi, Ankara. Erişim adresi: http://www. isbs2015. gazi. edu. tr/belgeler/bildiriler/839-847. pdf*.

Demircan, R. K., & Gültekin, A. B. (2017). Binalarda pasif ve aktif güneş sistemlerinin incelenmesi. *TÜBAV Bilim Dergisi*, *10*(1), 36-51.

Kon, O. (2018) Calculation of fuel consumption and emissions in buildings based on external walls and windows using economic optimization. *Journal of the Faculty of Engineering and Architecture of Gazi University, 33(1)*, 101-113.

Mousavi Motlagh, S. F., Sohani, A., Djavad Saghafi, M., Sayyaadi, H., & Nastasi, B. (2021). Acquiring the foremost window allocation strategy to achieve the best trade-off among energy, environmental, and comfort criteria in a building. *Energies*, *14*(13), 3962.

Pamir, N. (2017) *Enerjinin iktidarı*. Hayygrup Yayınevi.

Rosti, B., Omidvar, A., & Monghasemi, N. (2020). Optimal insulation thickness of common classic and modern exterior walls in different climate zones of Iran. *Journal of Building Engineering*, *27*, 100954.

Sayadi, S., Hayati, A., & Salmanzadeh, M. (2021). Optimization of window-to-wall ratio for buildings located in different climates: An IDA-indoor climate and energy simulation study. *Energies*, *14*(7), 1974.

TÜİK 2023 (2024, April 4). *Adrese Dayalı Nüfus Kayıt Sistemi Sonuçları, 2023*, https://data.tuik.gov.tr/Bulten/Index?p=Adrese-Dayali-Nufus-Kayit-Sistemi-Sonuclari-2023-49684#:~:text=T%C3%BCrkiye'de%202022%20y%C4%B1l%C4%B1nda%20%93,dan%20%257'ye%20y%C3%BCkseldi.&text=%C4%B0stanbul'un%20n%C3%BCfusu%2C%20bir%20%C3%B6nceki,655%20bin%20924%20ki%C5%9Fi%20oldu

Ulusoy Şenyurt, S., & Altın, M. (2014). Enerji Etkin Tasarımın Çatı ve Cephelere Yansıması. *7. Ulusal Çatı & Cephe Sempozyumu*.

Urbikain, M. K. (2020). Energy efficient solutions for retrofitting a residential multi-storey building with vacuum insulation panels and low-E windows in two European climates. *Journal of cleaner production*, *269*, 121459.

Vincelas, F. F. C., & Ghislain, T. (2017). The determination of the most economical combination between external wall and the optimum insulation material in Cameroonian's buildings. *Journal of Building Engineering*, *9*, 155-163.

Yüksel, T. (2019). *Mevcut bir binanın yenilenmesinde pasif ve aktif seçeneklerin enerji verimliliği ve maliyet acısından değerlendirilmesi*. [Yüksek lisans tezi, Yıldız Teknik Üniversitesi]. https://tez.yok.gov.tr/UlusalTezMerkezi/tezDetay.jsp?id=-_P_Kl0Gw4XTIVa0bytcVQ&no=C4qk86CidZdb5xkjZIYpzA