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Research Article

Evaluation of the Analysis of Daylight Performance for Public Buildings Facade Design Improvement

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Keywords

Carbon footprint,
Climate change,
Municipal buildings,
Facade design.

Abstract

Global climate change threatens the ecosystem and has long-term consequences for societies. Human activities, particularly the use of fossil fuels, contribute to global warming due to greenhouse gas emissions. According to reports from the Intergovernmental Panel on Climate Change in 2001, 2007, and 2013, human activities have been identified as the primary cause of global warming observed since the mid-20th century. Factors contributing to global warming and climate change include energy consumption for electricity and heating, the use of fossil fuels, and the emission of greenhouse gases. Daylighting is important in ensuring the space's energy efficiency, sustainability, and comfort conditions. By incorporating sustainable building envelope designs, achieving the recommended daylighting levels is possible. This article examines the role of facade design in providing sustainable Energy for lighting and its impact on carbon footprint. The case study of the Kayseri Metropolitan Municipality building and the analysis of daylight levels in its spaces serve as a guiding example for the renovation of public buildings. Thus, new methods can be determined to reduce daylight-related electricity consumption with appropriate and straightforward decisions in designing the facades of the working areas of public buildings in Turkey.

1. Introduction

In their study, Bitaab et al. (2018) express the qualities of a healthy city as sustainable revival, safety and security, economic efficiency, cooperation, access, balance, compatibility, dynamism, identity, beauty, variety, leisure efficiency, a closed city, and a feeling of belonging. These principles constitute a healthy city's basic characteristics and realization conditions [1]. Sustainable development and economic efficiency can be attributed to factors such as energy efficiency, users, buildings, etc., in the correct planning of the organization of cities. In the literature are reports of international organizations, country policies, and laws on concepts such as energy efficiency, energy efficiency in buildings, and sustainability. Building energy demands are increasing with the rapid development of society and the economy. According to the 2018 global energy consumption and carbon emissions data from the International Energy Agency (IEA), the energy associated with the construction and post-construction use of buildings accounts for 35% of total energy consumption [2]. Improving building energy efficiency reduces carbon emissions and helps to achieve national targets for sustainable development. Building energy efficiency needs to be addressed through a scientific evaluation method to control energy costs, environmental pollution, and carbon

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emissions without compromising the comfort conditions of the building's heating, cooling, and lighting systems. According to the 2021 report from the International Energy Agency, the most significant increase in CO_2 emissions by sectors has been in electricity and heat generation (Figure 1). The report states that fossil fuels used in electricity generation account for 46% of the global increase in carbon emissions [3].

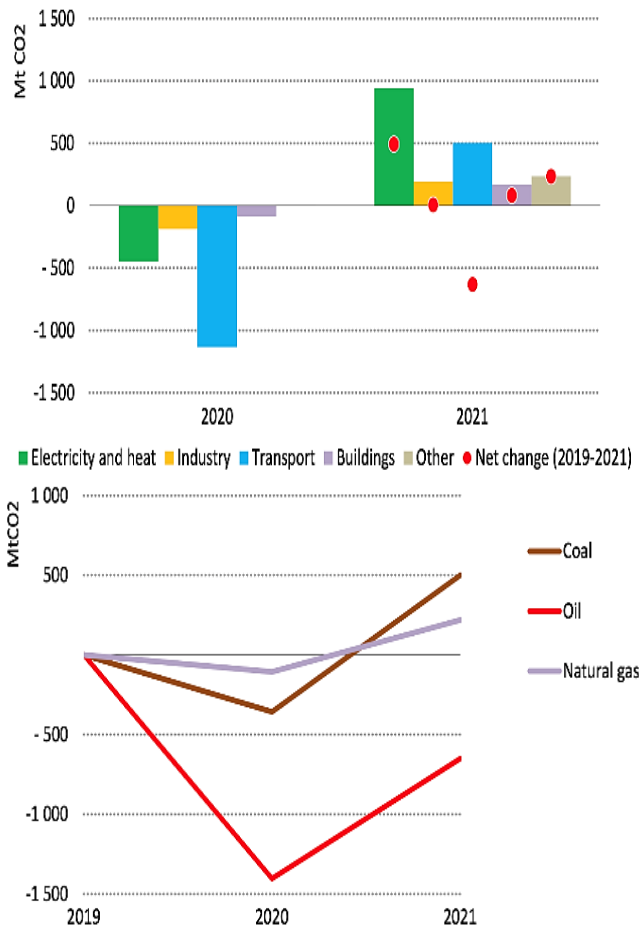


Figure 1. Distribution of carbon emission rates between 2019 and 2021 by sectors and increase in carbon emission rates due to fossil fuels used [3].

According to the same report, the economy significantly affects CO_2 emissions. While developed countries have mainly separated economic growth from emissions, a significant relationship exists between greenhouse gas emissions and developing economies. Population growth, increased building services and comfort levels, and increased time spent in buildings have led to higher energy consumption, approaching the levels seen in transportation and industry [3] (Figure 2).

In the International Panel on Climate Change (IPCC) 2007 report, it was aimed to make policies by the specified dates to reduce CO_2 emissions related to what needs to be accomplished about climate change and the measures that societies should take [4] (Table 1). The main issues in building performance are energy consumption and the user's thermal, visual, and acoustic comfort. Nearly Zero Energy Buildings (nZEB) are recognized as highly energy efficient buildings supported by renewable energy to reduce the increasing demand.

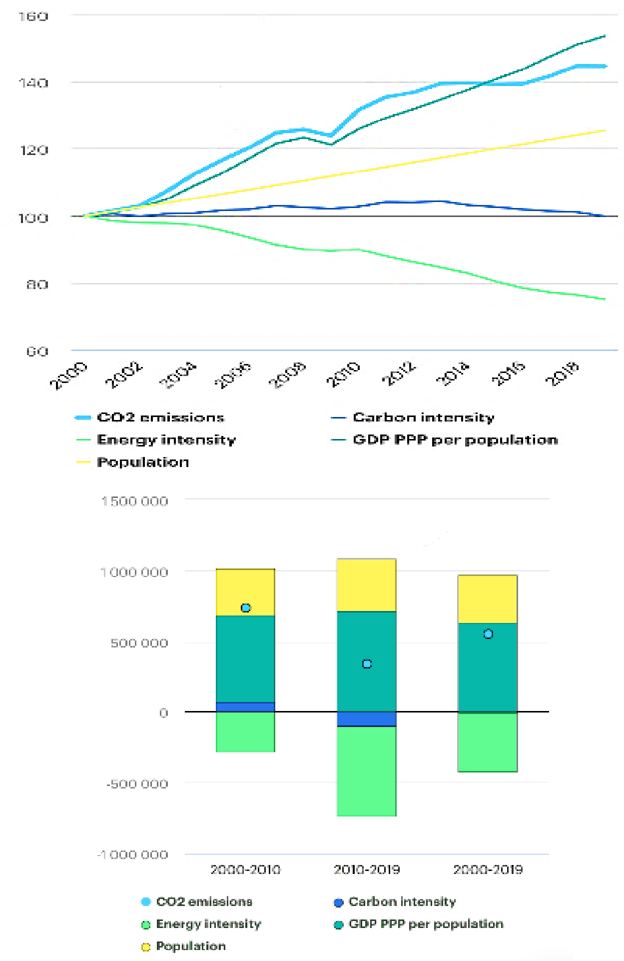


Figure 2. Relationship of carbon emission rates between 2019 and 2021 with population growth [3].

According to Jin et al. (2019), the issues that should be considered in the energy analysis of buildings at the detailed design stage are listed as follows:

- Detailed energy use analysis and performance-based assessments, including "lighting and daylighting analysis, sun and shade analysis, airflow and ventilation analysis," that provide comprehensive information
- Analysis of greenhouse gas emissions and carbon footprint
- Comfort of living analysis
- Cost analysis [5].

According to the 2022 study by the European Building Performance Institute (BPIE), offices and public, educational, and commercial buildings constitute the majority of energy consumption among non-residential structures [17] (Figure 3). The situation in Turkey, based on the 2019 data from the Turkish Statistical Institute (TÜİK), shows that 87.4% of CO2 emissions originate from the energy sector, with 34.6% attributed to electricity and heat generation. Furthermore, according to TÜİK's 2021 data, the share of electricity consumption in public buildings is 4.9% [18].

Table 1. Targets and definitions to realize the Zero Energy/Nearly Zero Energy Building (nZEB) target

Legislation	Country/Year	Target/Date planned for realization
Energy Performance in Buildings Directive (EPBD) [6]	European Union Countries /2010	All new buildings should be nearly zero energy (nZEB). /2019 All public buildings should be nearly zero energy (nZEB). /2021
IEA's energy policies: The case of the UK [7] [8]	UK /2007	All new-build housing should be zero carbon. /2016
Belgian federal government's definition of zero-energy housing [9] [10]	Belgium/ 2012	All new buildings should be nearly zero energy (nZEB). /2020
US federal government [11]	US/2007	50% of public buildings should be zero energy. /2040 All public buildings should be zero energy. / 2050
NASA, Zero energy building [12]	US/2010	All NASA structures must be zero energy. /2020
California Public Utilities Commission [13]	California/ 2008	All new housing should be zero energy. /2020 All new public buildings should be zero energy. /2030 Retrofit projects should be carried out for 50% of public buildings to be zero energy. /2030
Ministry of Economy, Trade and Industry [14]	Japan/2014	All new housing should be zero energy. /2050
Energy Council [15]	Australia/2019	Residential and public buildings should be zero energy. /2030
Turkey's National Energy Plan [16]	Turkey/2022	The use of renewable energy sources should be increased. /2035 Net zero emissions in all sectors. /2053

Reducing energy consumption in existing public buildings is important for reducing costs and environmental impacts and demonstrating governments' strong commitment to reducing greenhouse gas emissions. Successful energy efficiency improvement projects in buildings offer benefits such as providing insights into what should be included in retrofit projects for energy-efficient use and/or how calculations should be performed for other sectors responsible for energy consumption and greenhouse gas emissions, such as commercial buildings.

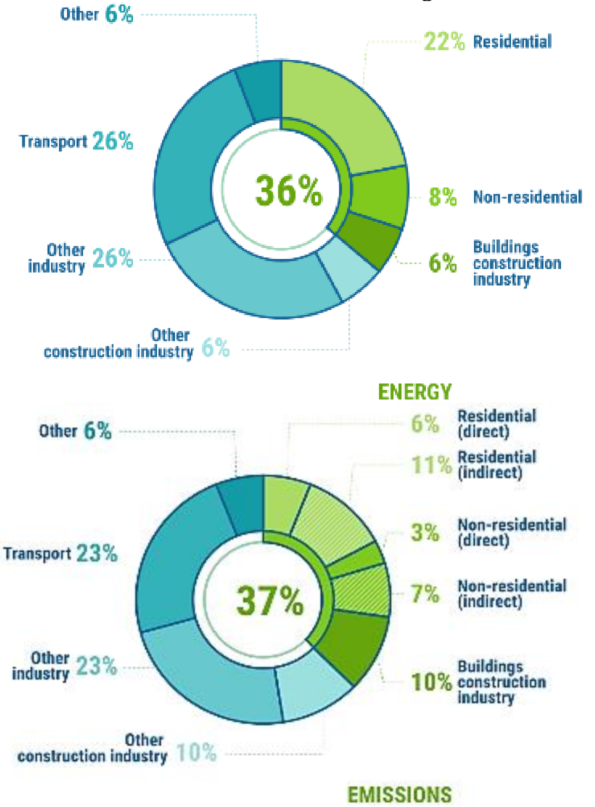


Figure 3. Energy consumption rates between buildings [17].

2. Literature Review

The literature has studies linking building envelope design, sustainable solutions, building energy efficiency, and carbon footprint (Table 2). Lizana et al. (2018) proposed a modeling approach to the energy-efficient use of heating, cooling, and lighting systems in educational buildings [19]. Shrestha & Kulkarni (2010) introduced the concept of "Energy Use Intensity (EUI)" to evaluate building energy efficiency [20]. Gonzalez et al. (2011) developed the "Energy Efficiency Building Index (EEBI)" to compare actual energy consumption [21]. Ahmad et al. (2012) proposed the concept of the "Energy Efficiency Index (EEI)", which includes information about energy input and equipment information where energy is used [22]. Emmanuel et al. proposed the Climate Energy Index (CEI) and the Building Energy Index (BEI), considering the climate impact on energy efficiency assessment [23].

These methods mentioned in the literature evaluate building energy efficiency through a single parameter related to energy consumption. While single-parameter evaluation methods offer simplicity and ease of use, they overlook the building function and the user. In addition to these methods, there are evaluation systems such as Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment (BREEAM), Green Globes, Green Building Council of India, Comprehensive Assessment System for Built Environment Efficiency (CASBEE), and The National Australian Built Environment Rating System (NABERS) where energy efficiency is evaluated with multiple parameters. These assessment methods encompass all aspects of building performance, including site plan, materials, energy, indoor environmental quality, and other relevant information about the building.

According to the energy efficiency assessment by the European Commission, it is recommended to renovate buildings at an average annual rate of 3% to achieve the cost-effective zero greenhouse gas mission target by 2050. It is well-known that a 1% increase in energy savings can reduce the demand for natural gas by 2.6%. Therefore, targets for renovation or retrofitting the existing building stock are significant [24]. Practices to improve the energy performance of buildings should not solely focus on the building envelope but should also incorporate sustainable techniques to reduce energy requirements. These practices should improve energy efficiency and comfort conditions related to heating and/or cooling, lighting, and ventilation.

Table 2. Relationship between sustainable solutions and architectural design

	Arch. Design	Daylighting	Technology (New/Old Project)	Retrofit
SUSTAINABLE DESIGN (Energy efficiency, embodied energy)	Shape, form Space/ Interior design (Furnishing, Surface design)	Availability (Sidelight/ Skylight) Window to Wall ratio (WWR) Climatic Conditions (Sky type) Space location/ orientation/ direction	Measurement technology (HDR, Luminance meter, Illuminance meter, etc.) Control algorithm (ML, AI, RL, etc.) Simulation design (Revit, BIM, Rhino, DIVA, RADIANCE, etc.)	Photosensor (Type, positions, response), Open/closed loop, Shading integration, Occupancy strategies, Local manual control, Luminaire/Lighting device (Lamps, Ballasts, etc.), Space/ Surface design

In protocols and future targets outlined for achieving the specified reduction in carbon emissions, it is important to measure and/or calculate emissions. In Turkey, the protocols currently in effect are the Vienna Convention and Montreal Protocol, the UN Framework Convention on Climate Change, the Kyoto Protocol, and the Paris Agreement. The common objective of these protocols is to control and monitor greenhouse gas emissions. Looking at the world in general, the Kyoto Protocol stands out as the most successful measure to be taken against greenhouse gas emissions. The Kyoto Protocol aims to control the emissions of countries responsible for at least 55% of the greenhouse gas emissions in the world. Turkey became a party to the protocol in 2009 and has no quantified emission limitation and/or reduction obligation.

Nevertheless, ongoing efforts are in place, per other protocols, to reduce greenhouse gases [25]. The Kyoto Protocol focuses on six greenhouse gases, each with varying carbon emission values [26] (Table 3). Turkey's CO_2 emissions from electricity consumption are increasing day by day, emphasizing the growing importance of protocols and implementation methods (Figure 4).

Table 3. Greenhouse gases and their carbon emission rates based on the Kyoto Protocol [26].

Symbol	Name	CO_2 Equivalent	Source
CO_2	Carbon Dioxide	1	Combustion of fossil fuels, forest fires, cement production
CH_2	Methane	21	Landfill sites, production and distribution of oil and natural gas, fermentation in the digestive systems of farm animals
NO_2	Nitroxide	310	Fertilizers, nylon production, N_2O combustion of fossil fuels
HFC_s	Hydrofluorocarbons	140~ 11.700	Refrigerator gases, aluminum smelting, semiconductor production
PFC_s	Perfluorocarbons	6.500~ 9.200	Aluminum production, semiconductor production
SF_6	Sulfur Hexafluoride	23.900	Electricity transmission and distribution systems, magnesium production

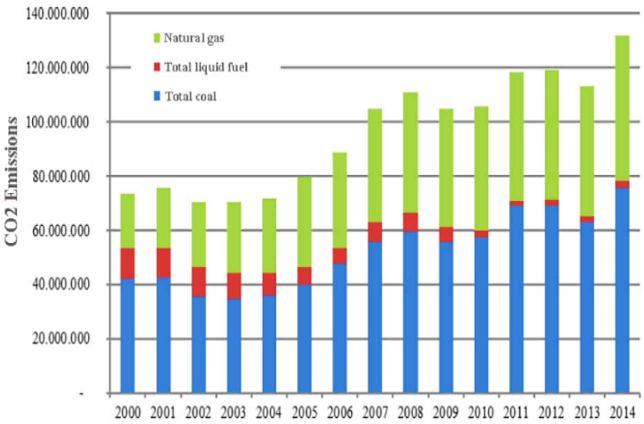


Figure 4. CO_2 emissions from electricity generation in Turkey (according to TEİAŞ data)

The basic criteria of lighting design in sustainable architecture include;

- Ensuring the desired visual comfort conditions in the volumes,
- Providing psychologically and physiologically appropriate lighting design to enhance user satisfaction,
- Developing solutions to minimize energy consumption required for lighting,
- Selection of lighting systems with minimum environmental impact and realization of designs by considering the concept of optimal cost [27].

When considering the criteria for sustainable lighting design, it is possible to reduce the energy required for lighting by utilizing natural daylight when it is sufficient. Daylighting consists of the distribution of *luminance* from the sun and the sky. The daylight availability varies based on the building's geographical location (latitude and longitude), climatic conditions, and the sun's position (altitude and azimuth). The latitude at which the building is located determines the sun's position at a specific time of the day or year. Determining the sun's position influences decisions such as the orientation of the building, the type and area of windows, and the design of shading elements [28]. For instance, the north-facing facades of a building in the northern hemisphere receive less daylight than windows facing other directions. Daylight from this direction consists of diffuse light and remains constant throughout the day. However, daylight from the south, east, and west is usually direct daylight, and levels vary throughout the day [27]. IESNA addresses sustainability in lighting design under three main headings (Table 4).

Table 4. IESNA's recommendations on sustainability in lighting design [27].

Components	Attribute	Relevance	Significance
Energy	Controls	Limit electricity use	Photocells, Occupancy sensors, astronomical time clocks
Efficiency	Room surfaces(1) Ballasts/ drivers/ transformers (2) Lamps, luminaires (2) Layout	Maximize interreflection (1) Select the most efficient for class (2) Select the most appropriate for class (2) Establish efficient layout	≥90% /≥ 60% /≥ 20% (ceiling/walls/floor) (1) Highest efficiency /distribution (2)
Embodied energy	Production Transportation	Limit high-energy processes Limit volume and weight	Maximize overall carbon footprint

All sub-headings of sustainability in buildings and their interrelationships bring the facade design, a component of daylight distribution, heat transfer, thermal gains, and ventilation system, to the forefront. Facades, which significantly impact the building's energy efficiency and carbon emissions, provide a visual relationship with the exterior, create a boundary between the public space and the interior and provide security. Facade features are also at the forefront of retrofit projects in ensuring climate resilience due to their impact on the life cycle from the preliminary design phase to the use phase. However, after the construction-management phase, evaluating the ambient conditions with on-site measurements is essential regarding issues such as space management, ensuring comfort conditions, and providing the energy needed. The energy provided from sustainable sources and possible energy losses should be evaluated as a whole in building envelope design. All these evaluations ensure the efficient use of the life cycle and the reduction of carbon emissions (Figure 5).

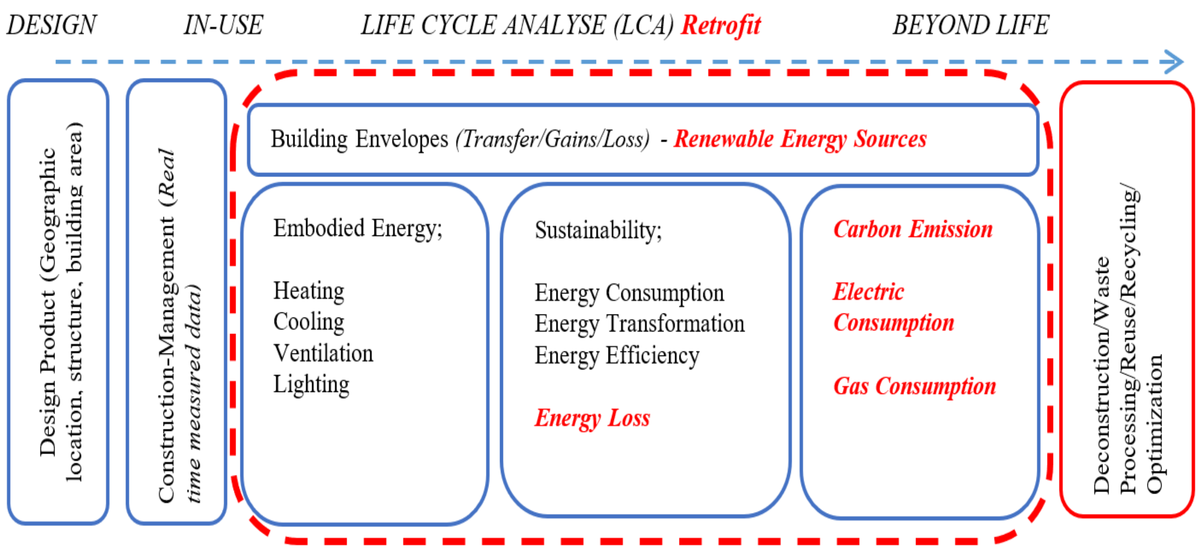


Figure 5. Building energy efficiency and consumption stages calculated in carbon emissions

3. Relationship Between Facade Design and Daylight Performance

Changes in the position of the sun and its orbit require unique design decisions. The external appearance can be structured by applying light shelves, recesses and protrusions, and other architectural features to diffuse daylight. During the design phase, the facade should be adapted according to the latitude where the building is located, the building openings, the needs of the area, and other sub-parameters in the design. Implementing shading elements on the facade can help reduce cooling loads and minimize the need for interior shading devices.

Solutions to protect windows from direct sunlight vary depending on the time of day, season, latitude, and orientation. In mid-latitudes, it is possible to use horizontal elements for maximum benefit on the south-facing facade and both horizontal and vertical elements for maximum benefit on the east and west facades.

According to IESNA (2011), the factors to be considered in the design of exterior shading elements are listed as follows [27]:

- Processing of snow and ice accumulated on shutters and other elements, considering that it may fall later,
- Birds and nests gathering indoors,
- Cleaning and maintenance of windows and shading system

Olgyay & Olgyay (1957) list the design principles of the shading elements on the facade as follows [29]:

- Determination of the annual period when heat gain is undesirable,
- Determination of the annual and daily shading period according to the function of the space,
- Determination of critical sun angles,

- Determination of the physical properties of the shading device (number of elements, type, size, surface properties, etc.)
- It is known that selecting an optimum value for the window-to-wall ratio (WWR) will reduce energy consumption by half, as indicated by Arumi [30] and Johnson et al. [31]. Goia (2016) examined the optimum WWR in office buildings located between 35° and 60° latitudes in temperate and continental climate zones. It was stated that the optimal ratio effectively reduces the energy required for annual cooling, heating, and lighting. The results show that although there are optimum values in every climate and orientation, the ideal values can be 0.30<WWR<0.45 [32].

Daylighting can offer illumination throughout or most of the day with sufficient illumination levels indoors. Krarti et al. (2005) mentioned in their study that automated control of artificial lighting can reduce the energy requirement for lighting by 30% to 60%. This also means energy savings and lower carbon emissions. Moreover, it is possible to reduce the cooling load by reducing the power of artificial lighting during daylight hours [33]. Daylight, temperature, and user dependent automation recommendations for optimizing the energy required for artificial lighting are summarized in the table below (Table 5).

Table 5. Control methods and parameters for optimization of energy consumed [27]

	Components	Attribute	Relevance	Significance
CONTROLS	Daylight response	Shading	Glare	Comfort
		Electric lighting	Intensity modulation	Energy reduction
	Temporal response	Anticipated occupancy	Nominally based lighting	Energy reduction
		Setbacks	Modulate demand, limit available lighting	Energy cost reduction, limit light pollution
	Occupancy response	Actual occupancy	Need only	Energy reduction Extend in-service life

Manzan et al. (2017) suggested that the link between environmental comfort conditions and the energy efficiency of the building should be analyzed from the design stage and compared with post-occupancy data [34]. Tools, standards, and certifications that consider visual comfort, thermal comfort, and energy efficiency in building design can be utilized to improve these aspects. However, visual and thermal performance improvement should be considered in enclosure design through optical and thermal properties applied to windows and other facade components. According to IESNA (2000), all parameters related to user behavior, environmental conditions, and shading elements should be considered for successful retrofit [35]. For this reason, it is impossible to achieve energy-efficient building design without analyzing the effects of facade control elements and/or methods on building performance. In the study by Kang et al. (2023), it was focused on the identification of electrical loads. They aimed to reduce electricity consumption, determine improvement projects, and decrease carbon emissions by using a statistical model (which identifies the factors influencing a building's electricity consumption) and a lower-upper model (which considers user preferences/activities and the effects of socio-demographic factors) [36]. The study of Yang et al. (2023) focused on addressing the carbon emission caused by the energy consumption of public buildings at the district scale. They aimed to identify measures for improving educational buildings at the district level, considering the future status of district energy resources, country policies, and carbon emission mapping. These measures include reducing carbon intensity by reducing the energy required for lighting. For example, using high-efficiency devices determines effective methods to ensure visual comfort in spaces [37].

While facade openings provide daylighting and illumination, other building physics issues, such as heat losses and noise control, need to be addressed. The literature review includes the optimization of the building envelope and openings with parametric design. Wen et al. (2017) developed a modeling proposal for determining the WWR to be used in the energy performance evaluation of the office building during the preliminary design phase. They investigated various design conditions, including energy requirements, climate, window orientation, internal gains, and building scale for lighting in office buildings in Japan's different climate zones. As a result of the evaluation, it was determined that these design conditions significantly affected the window-to-wall ratio, the CO_2 emission of the structure, the optimum window-to-wall ratio in different climatic zones related to lighting efficiency, and the window-wall ratio on the facade (Figure 6) [38].

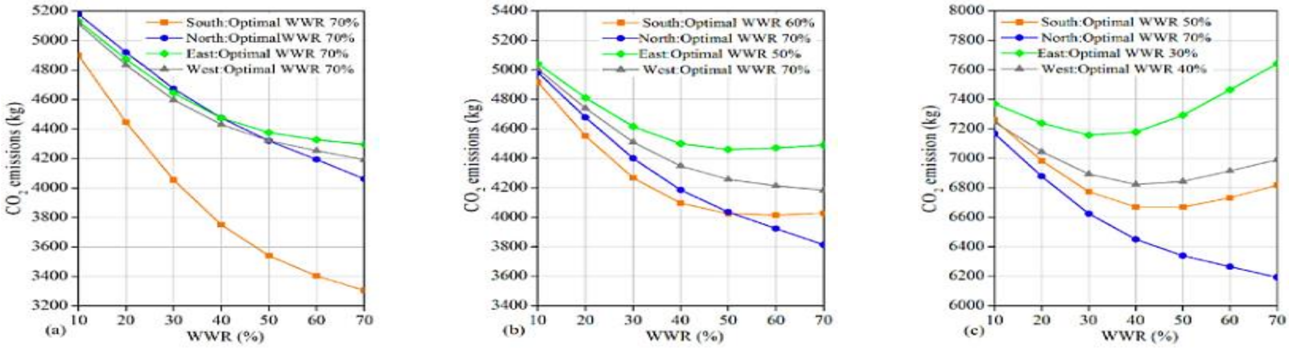


Figure 6. Effect of window-to-wall ratio on CO_2 emissions (Sapporo, Tokyo, and Naha examples) [38].

Susurova et al. (2013) proved that optimizing the building and window geometry (WWR, facade where the window is located, width-to-width depth ratio) in an office building can save up to 14% of energy consumption and improve building performance [39]. Numerous studies have investigated the impact on energy consumption. Lee et al. (2013) and Bülow-Hübe (2001) have stated that the window causes 20-40% of the wasted energy in a building [40] [41]. The window size is the most crucial factor in limiting heat loss or gain in the building envelope. However, in terms of daylight illumination in facade design, window characteristics (number of registers, properties of the glass, location, etc.) are important. Therefore, window design is a parameter that affects the energy performance of the building and provides natural light and external visibility (Table 6).

Table 6. Daylight and solar energy transmittance rates of different types of window glass [42].

Characteristics of window glass	Daylight Transmittance Rate	Solar Energy Transmittance Rate
Single glass	88%	83%
Double glazing	77-80%	65-70%
Double glazing-tinted	29%	39%
Three glasses	70%	40-60%

To effectively use daylighting within a space, accurately determining the outdoor illuminance level is essential. There are methods to determine and evaluate building performance by determining the outdoor illuminance level. There are two evaluation methods for daylighting: static and climate-based/dynamic daylighting simulations. These methods are given in Table 7.

Table 7. Static and climate-based daylighting parameters for daylighting

Static Calculation Method	Climate-based Calculation Method
Daylight factor *(Daylight Factor-DF)*	Daylight autonomy *(Daylight Autonomy-DA)*
Average Daylight Factor *(ADF)*	Continuous Daylight Autonomy (*DAcon or cDA)*
	Maximum Daylight Autonomy *(Maximum Daylight Autonomy-DAmax)*
	Useful Daylight Autonomy *(UDI)*
	Annual Sunlight Exposure *(ASE)*
	Spatial Daylight Autonomy *(SDA)*

The research by Mardeljevic et al. (2013) noted that the Daylight Factor decreases gradually in the depths of the volume regarding its distribution. They suggested that the architectural design should provide a daylight illuminance level of 300 lx at the working plane and a daylight factor value for half of the daylight hours (Figure 7) [43]. However, the Daylight Factor is an orientation-independent parameter. It is the most widely accepted rating criterion due to its simplicity of calculation. It is defined by calculating the most unfavorable overcast sky condition and giving better illuminance in other sky conditions. Most current standards continue to use the daylight factor [44].

Christoffersen et al. (2017) evaluated two volumes where the calculation of the Average Daylight Factor (ADF) value with the formula is the same. In their evaluations, they mention that the Average Daylighting Factor in the standards ignores the differences in facade design and is insufficient (Figure 8) [45].

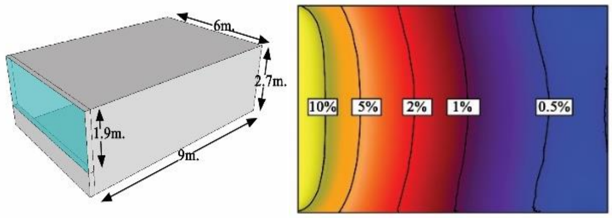


Figure 7. Variation of Daylight Factor depending on the depth of the volume. [43].

Currently, there is a growing trend to make design decisions based on the climate of the building's location and to perform evaluations for different sky conditions. Daylight calculation methods based on climate-based designs and their use are becoming widespread. In LEED v4.1 certification, daylight illuminance levels are required to remain within certain limits at specific points of the volume. These limits, related to spatial daylighting autonomy and annual daylighting, are based on stating that the 300-lux value is provided at least 55% at two points and at least 75% at three points of the volume. Additionally, in time-dependent measurements, it is recommended to conduct the second measurement between May and September, assuming that the first measurement is taken in January [46].

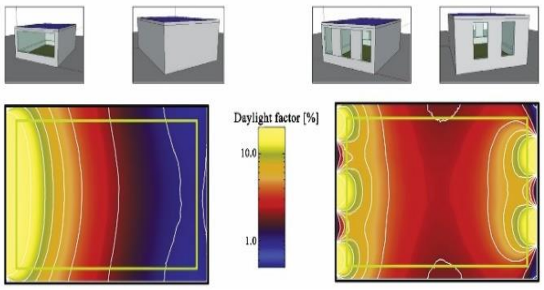


Figure 8. Cases where the Average Daylight Factor is the same as the calculation for volumes with different window-to-wall ratios [45].

Currently, there is a growing trend to make design decisions based on the climate of the building's location and to perform evaluations for different sky conditions. Daylight calculation methods based on climate-based designs and their use are becoming widespread. In LEED v4.1 certification, daylight illuminance levels are required to remain within certain limits at specific points of the volume. These limits, related to spatial daylighting autonomy and annual daylighting, are based on stating that the 300-lux value is provided at least 55% at two points and at least 75% at three points of the volume. Additionally, in time-dependent measurements, it is recommended to conduct the second measurement between May and September, assuming that the first measurement is taken in January [46].

4. Research Method

Mata et al. (2020) emphasized that the building sector accounts for 36% of total global energy consumption and 40% of carbon emissions [47]. The total carbon emissions of the building consist of operating energy (70%), the carbon content of the materials used in the building (6%), and the circulation of the building (24%) during the life cycle of the building [48]. Regarding public buildings, the 2018 CBECS study indicated that lighting energy consumption represents 24.8% of the total energy consumption [49]. In the report published in 2010 by the US Energy Agency, it was stated that this rate is increasing every year and will increase even more (Figure 9) [50].

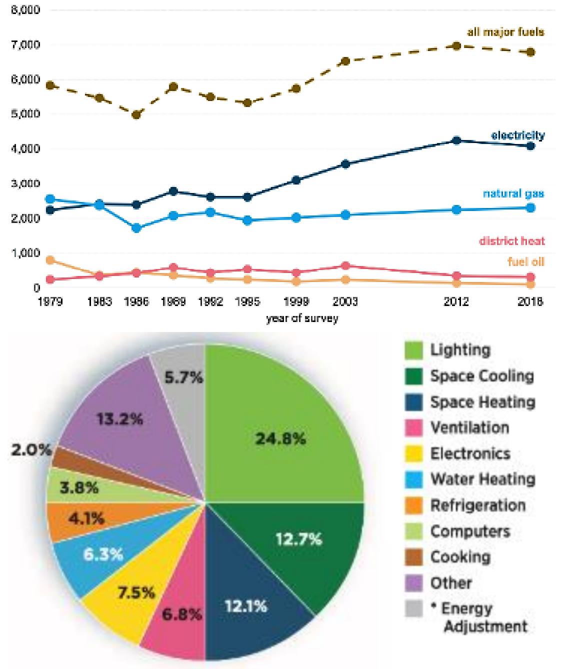


Figure 9. Representation of energy consumption intensity in public buildings according to the types of energy consumed [49] [50].

Energy consumption approaches of buildings contribute significantly to determining the utilization of different energy sources and estimating their use. Piper (1999) attributed energy consumption to the age of the building, occupancy factor (number of employees, hours of use), climatic factors, user behavior, maintenance factor, and the characteristics of the energy-supplying equipment [51]. The increasing complexity of modern energy systems used in old and new settlements necessitates searching for more innovative and reliable approaches. However, the complexity of optimizing energy consumption increases with differences in the use of electrical appliances, the geographical location of the building, the wear rate of the building, its function, and the behavior of users. The impact of renovation on building performance becomes crucial during the design phase, particularly in older settlements (Figure 10).

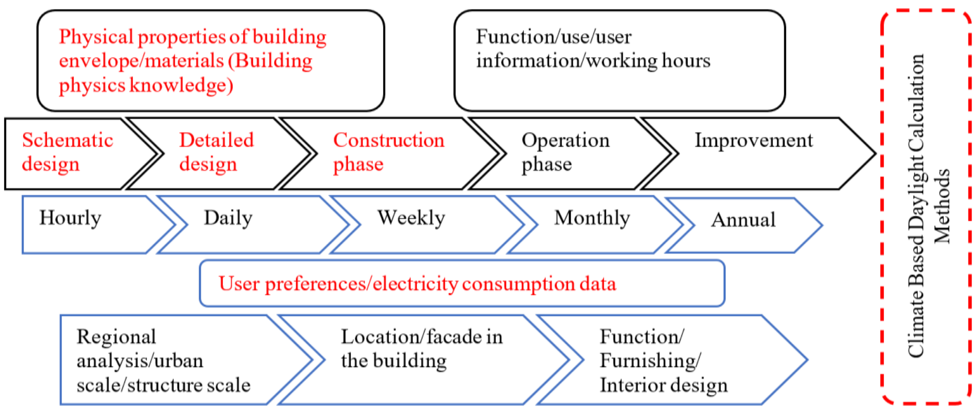


Figure 10. Parameters considered in the energy-efficient design of the building examined in the field analysis in the study

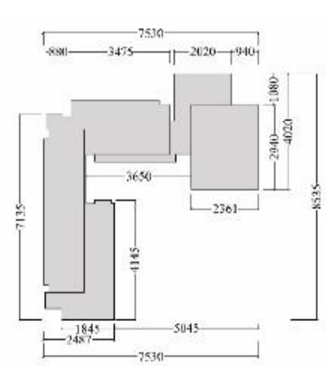
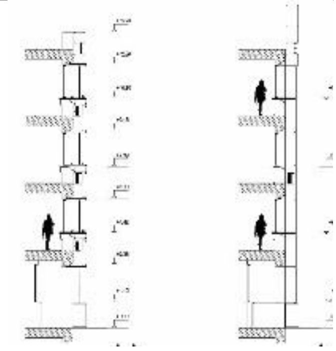
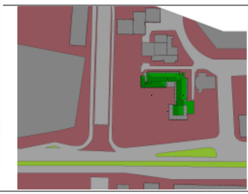
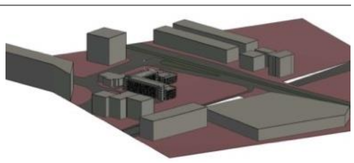
4.1. Building envelope specification and energy consumption data

Energy use in public buildings involves different parameters such as lighting, elevator, ventilation, heating-cooling, etc. This article examines the effects of facade design on energy efficiency and carbon emissions reduction in a public building in Kayseri (Table 8, 9), a province in the hot-dry climate region of Turkey. The effect of the existing facade design on the daylighting performance and the energy load of the building envelope for electricity is evaluated through the intensive use function of the building: offices. The research method of the paper is;

- Literature review on country policies applied in daylighting, visual comfort parameters (quantity/quality of illumination issues), facade design (transparency ratio, window glass, and its properties), building envelope properties (form, interior surfaces, furnishing, shading elements, etc.) and daylight calculation methods,
- Evaluation of the effect of facade design on energy consumption of Useful Daylight Autonomy (UDI), Spatial Daylight Autonomy (sDA), and daylight illuminance levels through Design Builder simulation program,
- Evaluation of different daylight metrics to determine which metric aligns with user comfort conditions in office spaces,

Assisting in proposing facade improvements and reducing carbon emissions.

Table 8. Photographs and Drawings of The Facade Features And Dimensions Of The Building [52]

			
Old Building Facade	New Building Facade	Facade Photo	Facade Photo
			
	Facades	Facades	
			
Building Dimensions	Bim Software -Modeltop View	Bim Software Model	Sections

Natural gas is used for heating, while air conditioning is used for cooling throughout the entire space. The impact of the heating-cooling load and other electrical loads on the building's energy consumption can be observed in Figure 11. Based on the on-site inspections and measurements, the comparison of the building envelope's U value with the recommended value in the current TS825 standards is presented in Table 10. The table indicates that the current situation does not meet the standards, and it is anticipated to increase heat consumption based on the climate zone of the building. However, the calculation scope of the study does not include the impact of the facade on the heat load.

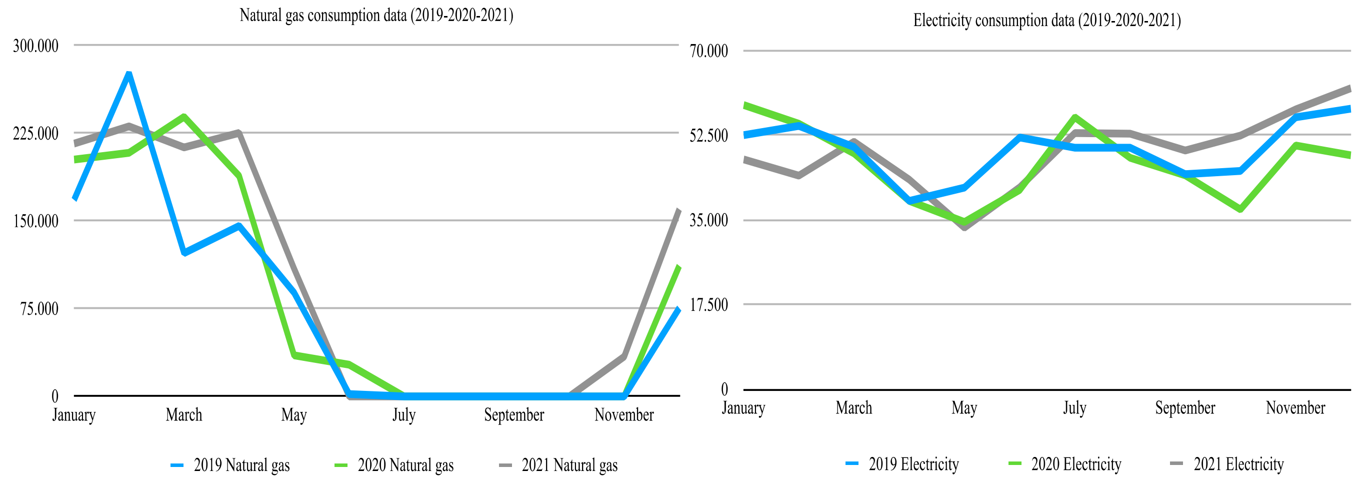


Figure 11. Kayseri Metropolitan Municipality Building energy consumption data (2019-2021) [52].

Table 9. Building shell and general information of Kayseri Metropolitan Municipality Building [52].

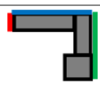
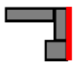
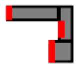
General information	Total Area (m)^2: 15.825						
	Building Length x Width (m): 25x72x73 						
	Number of occupancies :400						
	Number of zones (Independent sections) 200 (80% Office, 20% Other) *(8% of the independent sections do not receive daylight.)*						
	Working hours 08.00-17.30 (Weekdays)						
Building Shell	External wall (1) U_{wall1} (W/m^2 C)	External wall (column) (W/m^2 C)	(2) Earth U_{wall1} contact wall	Roof U_{roof} (W/m^2 C) *(Terrace)*	Roof U_{roof} (W/m^2 C) *Unused*	Flooring (2) U_{floor} (W/m^2 C) *Adjacent to the unheated indoor environment*	Window U_{window} (W/m^2 C)
	Plaster	Plaster	Plaster	Plaster	Polystyrene foam	Granite	Pvc 4+9+4+4 mm
	Brick	Reinforced	Reinforced	Reinforced	Plaster	Plaster	
	Plaster	Plaster	Plaster		Reinforced	Unreinforced Reinforced Stone fill/soil	
U (W/m^2 K)	1.050	3.390	3.922	3.81	0.983	0.799	3.2
A (m)^2	4097.84	694.96	831	56.02	2806.98	2863	1888.21
Facade cladding material	Wood-like composite panel cladding (dark walnut)	Aluminium sun shading panel with wooden sunshade (walnut)	Perforated aluminium composite panel (RAL 9001 cream)	Joinery color RAL 8025 dark brown	*Thermal insulation is not included*		
Facade Transparency rate (%)	Western Front 	Eastern Front 	Northern Front 	Southern Front 			
	34	60	31	87			
Sun shading (Horizontal direction) m^2	126	100	77	72			

Table 10. Comparison of the building envelope of the Kayseri Metropolitan Municipality Building according to the current situation and TS825 [52].

Reference value	U_{wall} (W/m^2 C)	$U_{ceiling}$ (W/m^2 C)	U_{floor} (W/m^2 C)	U_{window} (W/m^2 C)
TS825	0.400	0.250	0.400	2.4
Current situation	U_{wall1}: 1.050 U_{wall2}: 3.390	$U_{ceiling1}$: 0.983 $U_{ceiling2}$: 3.810	0.799	3.2

4.2. Lighting Conditions in Office Buildings

Energy saving in lighting, it is important to meet visual comfort conditions such as standardized illuminance levels, glare, and uniform distribution of light. Climate-based daylight calculation methods consider the efficient collection and distribution of daylight indoors and its impact on energy efficiency. Some studies include determinations for daylighting performance (Table 11).

4.3. Carbon Emission Calculation Methods

Analyzing and reducing production, service, and operational activities contributing to greenhouse gas emissions in architectural design products can help mitigate climate change. The energy intensity per unit area influences carbon emissions in buildings. Electricity, heat, gas, oil, and coal are energy sources associated with energy consumption in public buildings. Electricity consumption accounts for a significant portion of energy consumption in public buildings. The energy required for lighting represents 24.8% of the total energy consumption (Figure 9). The methods for calculating carbon footprint resulting from electricity consumption are outlined in Eq. (1) [62-63].

$$\mathbf{E_{tCO2/year}=((FV_{kWh/year}\ x\ EF_{kgco2/kWh}\ x\ I\&DK_{\%}) + (FV_{kwh/year}\ x\ EF_{kgCO2/kWh})) \ x\ 10^{-3}} \qquad (1)$$

Explanation of the formula: E_t CO_2: Emission of carbon dioxide in tons, FV: Activity data (kWh/year) Total annual electricity consumption, EF: Emission factor (kgCO_2 /kWh) (According to TEİAŞ data, it should be taken as 0.463 kgCO_2 /kWh for Turkey)., I&DK: Transmission and distribution losses (13.3% for Turkey according to TEİAŞ data),10^{-3}: Conversion factor from kg to tons.

4.4. Facade and Interior Analysis of the Offices Considered in the Daylight Performance Simulation

The locations of the offices in the floor plans, wall-window ratios, aspect ratios, daylight distribution based on climate, and interior surface reflectance multipliers are summarized below (Table 12, Table 13).

Table 11. Daylighting and Lighting visual comfort parameters in office buildings

Daylight parameter	Unit/metric	Criteria
Illuminance level	Daylight factor (Daylight Factor-DF)	DF is 5% or higher: The room has a bright daylight appearance. Daytime artificial lighting is usually unnecessary. High levels of daylight can be associated with thermal/glare problems. DF is 2-5%: Daylight can provide illumination, but artificial lighting is necessary for workplaces where activities are in progress. DF is less than 2%: lighting is insufficient and artificial lighting is necessary. [53]
	Useful daylight Factor (Useful Daylight Factor-UDI)	100 lux<UDI<2000 lux [44] [54]
	Spatial Daylight Autonomy-sDA	sDa=300 lux in at least 50% of the space [27] [55]
	Illuminance level	For office buildings, it is recommended that the illuminance level for users under 65 years of age be 320 lux (30 fc) in the working plane. [56] For vertical windows, 50% of daylight hours. 100 lx (minimum), 300 lx (medium), and 500 lx (high) at 95% of the reference plane for the targeted min. illuminance level or 300 lx (minimum), 500 lx (medium), or 750 lx (high) at 50% of the reference plane for the targeted illuminance level [57]. 300 lx (minimum), 500 lx (medium), 750 lx (high) at 50% of daylight hours for horizontal windows and 95% of the reference plane for the targeted min. illuminance level [57].
Distribution of illuminance level	The ratio of luminance distributions within the field of view	1:3:10 [27] The ratio of the illuminance level differences between the background and the main subject within the 60° viewing angle should be at most 1:3. The ratio of the illuminance level differences between the background and the main subject within the 120° viewing angle should be at most 1:10. [58] [59]
Glare	DGP	Non-high values indicate a low probability of uncomfortable glare. The minimum level of protection: $0.40 < DGP \leq 0.45$ [57]. Moderate protection: $0.35 < DGP \leq 0.40$ High level of protection: $DGP \leq 0.35$ (Maximum Permissible Exceedance Rate during Lifetime: 5%) [57] Calculation method with formula. $DGP = 5.87 \times 10^{-5} \times E_v + 9.18 \times 10^{-2} \times \log \left(1 + \sum \frac{L_{s,i}^2 \times \omega_{s,i}}{E_v^{1.87} \times P_i^2}\right) + 0.16$ E_v: Vertical illuminance at eye level (lx) L_s: Luminance of the glare source (cd/m^2) (for instance, the luminance of the sky and/or sun seen through the aperture in daylight apertures). P: Position index (-) (describes, for example, the reduction of glare perception by the angular displacement of the source from the user's line of sight). The position of the visible sky in the field of view at daylight apertures defines the magnitude of the position index; the position index decreases as observers move away from the center of view.) ωs: Solid angle of the glare source (sr) (The apparent size of the visible sky area in the daylight apertures to the observer's eye) i: Number of sources of glare. [60] [61].

5. Evaluation

The impact of facade design on daylighting conditions is well recognized, and it is understood that it is a primary factor in achieving visual comfort and aesthetics. The size of the windows and the size of the sun-shading panels significantly increase visual comfort. This study focuses on the analysis of daylight illuminance distribution after the renovation of the facade design. It is seen that the contribution of the renewed facade design to daylighting is almost negligible, sunshades are made with aesthetic concerns, and the building is handled independently of direction orientation and climate data.

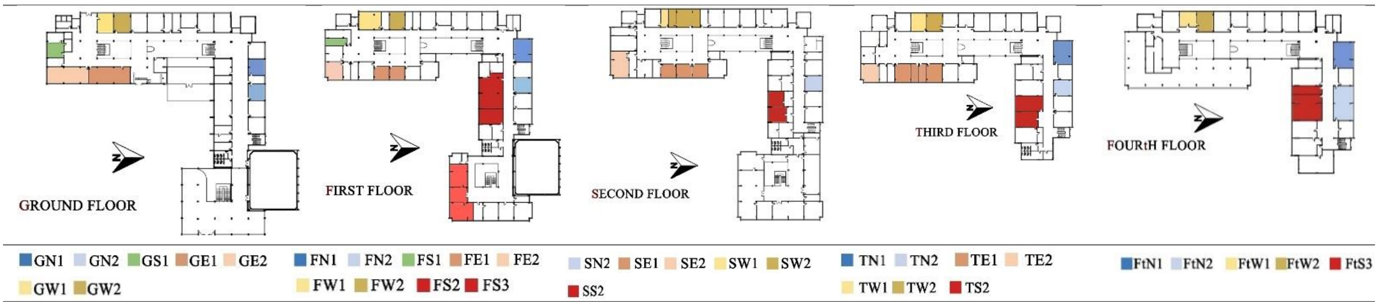
5.1. Analysis of Climate-based Daylighting Design Parameters Obtained in Simulation

The simulation was conducted in compliance with LEED v4.1 guidelines, which examine the annual performance of daylighting considering daily and seasonal variations in quantity and conditions. The calculations are based on the building's location and the annual daylight illuminance levels (Table 14).

Table 12. Selected spaces- Space Features

Kayseri Metropolitan Municipality Building Plans

GROUND FLOOR	FIRST FLOOR	SECOND FLOOR	THIRD FLOOR	FOURTH FLOOR



FACADE	Ground floor	First Floor	Second Floor	Third Floor	Fourth Floor
North	GN1: 73% GN2: 69%	FN1: 62% (5 m^2 sun shading) FN2: 62% (2.6 m^2 sun shading)	SN2: 62% (3.3 m^2 sun shading)	TN1: 62% (3.3 m^2 sun shading) TN2: 62% (1.3m^2 sun shading)	FtN1: 62% (3.3m^2 sun shading) FtN2: 62% (6.4 m^2 sun shading)
South	GS1: 75%	FS1: 85% (1.6 m2 sun shading) FS2: 62% (8 m^2 sun shading) FS3: 62% (8 m^2 sun shading)	SS2: 62% (8 m^2 sun shading)	TS1: 62% (1.6 m^2 sun shading TS2: 62% (8 m^2 sun shading)	FtS3: 62% (8 m^2 sun shading)
East	GE1: 60% GE2: 60%	FE1: 56% (3.2 m^2 sun shading) FE2: 62% (5 m^2 sun shading)	SE1: 56% (3.2 m^2 sun shading) SE2: 62% (5 m^2 sun shading)	TE1: 56% (1.6 m^2 sun shading) TE2: 62% (6.4 m^2 solar shading)	-
West	GW1: 83% GW2: 81%	FW1: 62% (3.3 m^2 sun shading) FW2: 62% (3.3 m^2 sun shading)	SW1: 62% (3.3 m^2 sun shading) SW2: 62% (1.6 m^2 sun shading)	TW1: 61% (3.3 m^2 solar shading) TW2: 62% (1.6 m^2 solar shading)	FtW1: 61% (3.3 m^2 sun shading) FtW2: 62% (1.6 m^2 sun shading)

General information for all units***;***
Surface reflectance multipliers for all units;
Wall: 70%; Floor: 50%; Ceiling: 80%, Floor height:266 cm, Parapet height 80 cm, Window sills:100cm, Calculation surface height: 76 cm, Specifications of the lighting device used for artificial lighting; Type: Surface-mounted fixture, Lamp: LED lamp

Table 14. Comparison of Results

Climate-based daylight parameter	Description	Optimum value range
Useful Daylight illuminance *(UDI)*	When daylight illuminance is between 100 lx and 2000 lx (UDI100-2000), proper daylight occurs.	<100 lux (fell short) >100 lux and< 300 lux (supplementary) >300 lux and< 3000 lux (Autonomous) >3000 lux (exceed) [53]
Spatial Daylight Autonomy *(SDA)*	It examines the acceptable level of daylight intake by including the volume in the usage period of the volume. As a result of the analyses made on the working spaces, the target illuminance level was determined as 300 lx. It is desired to provide this value for 50% of the volume (floor area) during the usage hours considered 08.00-18.00 (10 hours). Research revealed that for a given volume, users find the daylight level acceptable when sDA300>50% and are more satisfied when it exceeds 75% and approaches the feasible upper limit of approximately 95%.	sDa=300 lux in at least 50% of the space [54] [26]

Table 13. Daylight Distribution Based on Climate

The Useful Daylight metric (UDI) and Spatial Daylight Autonomy (SDA) design parameters were considered in the analysis. UDI is evaluated in three illuminance ranges: 0-100 lux, 100-2000 lux, and 2000 lux. Therefore, in the simulation, the upper threshold for color evaluation was set at 2000 lux, while the lower threshold was set at 50 lux. It is known that visual comfort conditions are achieved within the range of 100 lux to 2000 lux, while they are not met in other cases. It was observed that the 2000 lux threshold is exceeded in the examined spaces, indicating the presence of excessive glare and potential heat increase due to excessive daylight.

In most of the places where the sDA parameter is examined, it is seen that the value of 300 lux is provided in 50% of the volume (floor area). In contrast, in some places (TS2, FtW2, TW1, SW1, SW2) the window ratios are insufficient to provide the illuminance level in the depths of the volume. Analysis reveals those users near the windows experience high levels of illuminance and encounter issues with glare. It can be noted that the updated sun shading panels, intended to mitigate glare risks on screens in office spaces, are inadequate and implemented with flexible concerns. One of the measures that can be taken is to make contrast measurements depending on the user location in the volumes and to organize the interior design accordingly. Simulation data indicates that the placement of sun shading devices on the facade is not adequately adjusted based on daylight design parameters such as the depth of the space and the window-to-wall ratio (WWR). For example, although FS1 has a window-to-wall ratio of 85%, it is observed that the illuminance level in the depths of the volume does not meet the comfort conditions and the sun shading panels on the facade have a negative effect. Carbon emissions from artificial lighting are as Eq. (2)

$$\mathbf{E}_{tCO2/year}=((\mathbf{FV}_{kWh/year} \mathbf{\ x\ EF}_{kgco2/kWh} \mathbf{\ x\ } I\&\mathbf{DK}_{\%}) + (\mathbf{FV}_{kwh/year} \mathbf{\ x\ EF}_{kgCO2/kWh})) \mathbf{\ x\ 10}^{-3} \quad (2)$$

Calculation with the formula (Eq. (3))

$$E_tCO_2 = ((554746.29x0.463x13.3)+(554746.29x0.463))x10^{-3}$$
$$E_tCO_2 = (3416072.18+256847.53)\ x10^{-3}$$
$$E_tCO_2 = 3672.919 \quad (3)$$

Kneifel (2010) determined that using traditional energy efficiency methods without major changes in building design reduces energy consumption by an average of 20-30%. It was stated that other methods, such as facade improvement, have high initial investment costs but reduce the building's impact on climate change and carbon emissions [64]. It is seen that building features such as the WWR of the building envelope, the depth of the window sills, and the sunshade panels are among the essential parameters in reducing the electrical energy required for lighting. It was determined that the renewed facade design was not made with parametric calculation methods based on daylight but was renewed with aesthetic concerns. It is known that using parametric calculation methods of the facade-related results can reduce the analysis of the carbon emission intensity from electricity.

In Sweden, the electricity used for lighting in non-residential buildings accounts for 25-30% of the total energy consumed. A survey of 123 office buildings of different ages in Sweden showed an average annual energy density of 21 kWh/m2 yr for office lighting and an average installed lighting power density (LPD) of 10.5 W/m2, which varies according to room type: 13.1 W/m2 for individual office rooms, 12.4 W/m2 for landscape offices, and 8.6 W/m2 for standard rooms (including corridors) [65] [66]. According to Borg (2005), an existing office consumes about 23 kWh/m2 yr for artificial lighting, while a new office uses 11 kWh/m2 [67]. However, in cases where occupancy and daylight sensors are installed, consumption can be reduced to 5 kWh/m2 yr. In Bülow-Hübe's (2008) research, assuming an LPD value of 12 W/m2, the annual electricity consumption was determined as 28 kWh/m2 if the lighting is used 9 hours a day and 5 days a week. In cases where on-off manual systems are used, it is 20–23 kWh/m2 yr. When systems such as the use of sensors and dimmering systems are included, the electricity consumption required for lighting is in the range of 11-18 kWh/m2 yr [67]. Santamouris et al. (1994) studied the energy consumption of 186 office buildings in Greece. In their study, they determined that the average energy consumed for construction lighting is in the range of 15-25 kWh/m2 yr, depending on the type of building [68]. According to the LENI calculation method in EN-15193, the LPD for individual office spaces is 10 kWh/m2. Considering the reference annual usage time (2500 hours) and various lighting strategies, annual energy consumption varies between 7-20 kWh/m2. In large office buildings (>12 m2), annual energy consumption ranges between 30-17 kWh/m2 yr depending on the lighting control strategy selected, aiming for LPD below 12 W/m2 [69].

6. Conclusion

Due to climate change and the energy crisis, many countries worldwide (such as China, the European Union, and the United States) have established protocols to address the reduction of carbon emissions. The United States aims to reduce carbon emissions by 50% by 2030 compared to 2005, while the European Union Members target a 55% reduction by 2030 compared to 1990 [70]. During the 2020 United Nations General Assembly, the Chinese government announced its commitment to maximize the reduction of CO_2 emissions before 2030 and achieve carbon neutrality by 2060. In China, the construction sector is one of the three main areas of high energy consumption [71]. In this context, governments have established implementation methods of solar-based energy systems, five-year improvement plans for green building design, and physically based Urban building energy modeling (UBEM) from city scale to building scale to enhance energy efficiency and reduce carbon emissions in buildings. Gaps in carbon emissions and energy consumption in developing countries such as Turkey can be listed as,

- The inefficiency in current practices is limited to the individual building scale,
- Insufficient standards and regulations regarding energy usage,
- Existing limitations and regulations for buildings remain at the level of construction limits specified in zoning plans,
- Uncertainties regarding daylighting design in measures and improvement proposals for energy efficiency, optimization of energy consumption and carbon emissions,
- Lack of detailed research on building characteristics (such as number of floors, building type, year of construction, hours of use, etc.) and a registered system for an energy assessment of the existing building stock,
- Failure to address topics such as simulation analysis (including machine learning, statistical methods, and parametric design tools), latitude-longitude information, climate data, orientation, and the use of physical simulation tools considering future climate predictions in the early design stage.

Building performance-oriented designs requires integrating simulation and optimization tools from the early stages of the design process. According to the reports of international organizations, buildings account for 36% of carbon emissions. Measures aimed at reducing energy consumption are crucial in lowering carbon emission rates associated with buildings. Organizations such as the European Union Commission, ASHRAE, IEA, and IPCC aim to increase the number of nZEB-oriented buildings by 2050 and to control greenhouse gas emissions in the fight against climate change. According to the US 2019 energy consumption reports, approximately 125 million residential and commercial buildings consume approximately 412 billion USD of energy. With the projected increase in population density and the corresponding demand for buildings, failure to address energy efficiency issues would lead to a potential 65% surge in overall energy consumption [72].

In addition to sustainability and reducing carbon emissions, daylighting is important for visual comfort and green building design [73]. Adequate daylighting and energy savings for artificial lighting in public buildings can be achieved through proper control systems that ensure sufficient daylight illuminance levels [74]. Estimating the daylight illuminance level in the volumes with parametric design tools requires a holistic approach to aesthetic concerns and building performance in the preliminary design phase (Figure 12).

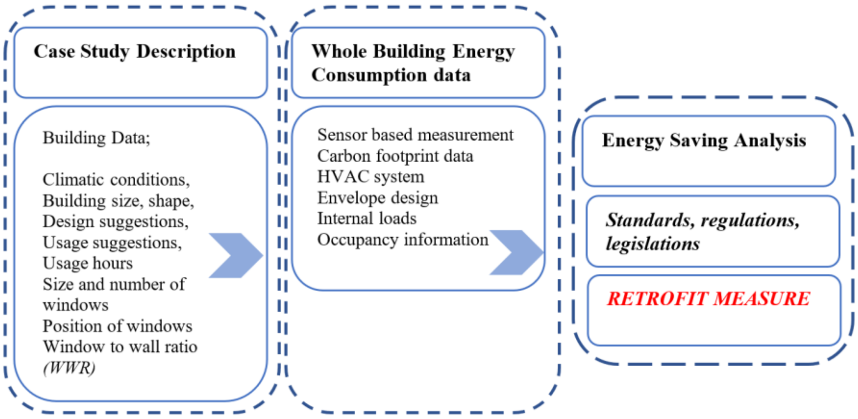


Figure 12. Interaction of energy consumption and carbon footprint in design

It is necessary to include issues such as the functioning of public buildings, the correct determination of energy consumption data, the regulation of the scope and method of energy consumption, the use of parametric design tools in improvement projects, benefit of energy-efficient technologies. Implementation guidelines for increasing the use of renewable energy sources and policies that encourage the use of new technologies that extend the life of the building in improvement projects should be developed. These policies are important in terms of life-cycle energy savings and reduction of embodied CO2 emissions. Electricity consumption in public buildings the uncertainty of energy efficiency standards and intervention methods are among the difficulties encountered in the use of sustainable energy. Although façade design suitable for daylight is a short-term analysis, most public buildings in Turkey are not taken into account in facade renovation processes. Correcting this situation and reducing daylight-related carbon emissions in public buildings in Turkey is considered as a possibility as a result of the study.

Conflict of Interest Statement

The authors declare no conflict of interest.

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