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A Study on the Applicability of Energy Efficient Design Approaches in Airport Terminal Buildings

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Abstract

Studies on energy efficiency and effectiveness, which have come to the agenda with the danger of depletion of natural resources and problems in energy supply, have started to find a response in the rapidly developing aviation sector as in many sectors. Airports consume large amounts of natural resources and energy during construction and operation processes. In this study, terminal buildings, which have the highest energy consumption in the airport complex, are considered. The aim of the study is to determine energy efficient design approaches that can be applied to provide efficiency in energy use in terminal buildings. In this context, through a literature review based on energy-efficient building design parameters, relevant regulations, aviation organizations' energy efficiency approaches, as well as the classification and evaluation of data obtained from sample building analyses, a guide has been developed for the energy efficiency-focused sustainable design of airport terminal buildings. This guide was then used to assess the Kahramanmaraş Airport Terminal Building as a case study. In the course of this research, it was determined that when designing airport terminal buildings with high energy consumption potential, special consideration must be given to the climatic region in which they are located. Design approaches should be shaped accordingly, taking into account factors such as land use, building orientation, building form, building envelope, shading elements design, design of renewable energy sources, location-transportation facilities, indoor environmental quality. Within this context, crucial design considerations pertaining to energy efficiency have been identified, and recommended solution strategies have been put forth.

1. INTRODUCTION

Energy dependence has witnessed a continuous rise in tandem with the advent of technological innovations accompanying the industrial revolution and the evolving lifestyles of individuals. A substantial fraction of global energy consumption is attributed to the construction industry. Within this sphere, the building sector commands particular attention as it exerts a notable demand on natural resources, relying heavily on energy throughout its lifecycle, commencing with the extraction of raw materials. In the operational phase of buildings, the lion's share of energy is allocated to meet heating, cooling, and ventilation requisites.

In parallel, the civil aviation sector, a swiftly advancing domain on the global stage, has displayed an average annual growth rate of approximately 5% since the 1970s [1]. It is worth noting that merely 10% of aviation activities occur in-flight, while a staggering 90% unfolds on the terra firma, predominantly within airport precincts. This data underscores the profound impact of airports, whose capacities and numbers burgeon in response to escalating demands, not only in energy consumption but also in terms of environmental repercussions [2].

Airports function as pivotal hubs in the realm of aviation transportation, operating on both national and international scales. These multifaceted complexes, characterized by their diversity of buildings and distinctive features, exact a substantial toll on natural resources and energy, especially electricity,

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throughout their construction and operational phases. Notably, terminal buildings, where bustling user activity persists incessantly year-round, stand as prime energy consumers within airports. These architectural edifices entail disparate spatial requirements and command a substantial air conditioning load, thus contributing to over 50% of the total energy consumption within airport precincts [3].

The burgeoning emphasis on enhancing energy efficiency at both domestic and international levels, coupled with the quest for cleaner energy sources, has thrust energy-efficient airport building construction into the limelight, paralleling efforts within the broader building sector. Terminal buildings, owing to their outsized contribution to energy consumption and their potential to curtail this footprint, emerge as pivotal structures meriting meticulous scrutiny and action with regards to energy efficiency initiatives.

The topic of energy efficiency in airport terminal buildings has been a subject of extensive research scrutiny. Noteworthy studies by Alba and Manana (2016) have illuminated the primary energy consumption domains and energy sources within airports, shedding light on energy consumption trends within airport sections. Their work underscores the significance of HVAC (Heating, Ventilating and Air Conditioning) systems, lighting design, and airport management models in mitigating energy consumption, emphasizing the role of energy consumption modelling and simulations in fostering energy efficiency [4].

In a study by Wang et al. (2015), eight distinct airports in China were subjected to an examination of indoor environmental quality. Through physical measurements and surveys conducted with users, the research highlighted thermal comfort and air quality as two paramount facets influencing user satisfaction. It was revealed that the extensive glass surfaces in airports significantly contribute to increased heating loads in winter and cooling loads in summer [5].

Ramis and Santos (2013), in their research encompassing three international airports in Brazil with distinct climatic characteristics and passenger capacities, delved into the thermal comfort attributes of indoor environments. They underscored the adverse impact of capacity expansion on thermal comfort conditions at airports and the negative consequences of upgrading existing HVAC systems to cope with increased demand. Their work also emphasized that terminal buildings with natural ventilation capabilities exhibit superior thermal comfort levels, thus accentuating the importance of integrating natural and artificial climate control systems in future terminal designs [6].

Pichatwatana et al. (2017) conducted an analysis of the indoor environmental conditions of the Suvarnabhumi Airport Terminal building in Thailand, relying on physical measurements, surveys, and energy modelling. Their findings underscored the substantial contribution of the glass roof surfaces to the cooling load of the structure [7].

Yıldız et al. (2020) discussed the possibilities of utilizing renewable energy sources in airports to reduce energy costs and greenhouse gas emissions. They examined the impact of renewable energy systems on aviation operations, assessing their application challenges, financial, environmental, and technical opportunities, risks, and difficulties. The utilization of renewable energy in airports worldwide and in Türkiye was explored [8].

In a study by Anurag et al. (2017), the use of PV panels in airports was investigated. The research addressed concerns related to the integration and positioning of PV panels in a manner that does not hinder aviation activities. The study also outlined design parameters for PV panel systems and conducted modelling and simulation for PV panel design at Houghton County Memorial Airport, elucidating strategies to overcome technical barriers associated with PV panel implementation [9].

Akyüz et al. (2017) evaluated the impact of refurbishment and renovation of the building envelope of the International Hasan Polatkan Airport terminal building on heating energy consumption. Calculations were performed in accordance with TS 825 "Thermal Insulation Rules in Buildings," and changes in annual heating energy requirements and economic payback periods were determined. This study underscores the significance of the building envelope in enhancing energy performance and reducing energy-related costs in airport terminal buildings [10].

Abdallah et al. (2021) investigated the indoor thermal comfort conditions of the Assiut International Airport terminal building located in a hot-dry climate region. The study monitored and analysed indoor environmental data, including temperature, relative humidity, and lighting, for different functional areas of the terminal building during the summer months when cooling loads are high. The research revealed that a significant portion of electricity consumption in the sampled airport was attributed to HVAC systems, with artificial lighting also playing a crucial role. The study identified that the extensive glass facades and roof skylights significantly raised indoor temperatures. Adjusting HVAC setpoints and replacing lighting fixtures with energy-efficient alternatives were recognized as effective strategies for achieving energy savings. Furthermore, the research emphasized the importance of integrated climate control systems, combining natural and artificial means, in future terminal structures [11].

Baxter et al. (2018) adopted a holistic approach to the design and operation of airports, investigating energy consumption and energy efficiency potentials within airport premises, encompassing both the airside and landside domains of an airport facility. Their work highlighted energy-saving measures such as HVAC system optimization, LED lighting utilization, photovoltaic system installation, groundwater utilization for cooling, and sensor use in elevators and escalators. These measures were found to be instrumental in achieving substantial energy savings, as evidenced by a case study at Copenhagen Airport, where energy efficiency methods as described resulted in a savings of 26.80 GWh of energy between 2009 and 2016 [12].

Jiang et al. (2021) postulated that airports constitute ideal sites for PV panel installation, considering their electricity-dependent nature within the aviation sector. The study advocated that the challenge of the aviation industry's increasing dependence on electricity could be addressed by integrating PV systems into airport infrastructure. The research encompassed eight different airports in China, revealing that electricity demands could be met through PV panels. Comprehensive economic analyses underscored the profitability of PV panel systems when coupled with sound investment and operational strategies [13].

Upon a comprehensive examination of studies pertaining to energy efficiency in airport terminal buildings, it becomes evident that these investigations often fail to account for the specific design requisites imposed by different climatic regions. Furthermore, there appears to be a tendency to consider building design, land use, and operational phases in isolation, rather than as an integrated whole. In light of these scholarly gaps, this study seeks to address these deficiencies by categorizing design decisions that align with climatic data, including building orientation, form, and envelope, under the rubric of energy-efficient terminal building design. Additionally, this study evaluates land use, methods for harnessing renewable energy sources, and the significance of location and transportation access in energy consumption.

1.1. Statement and Purposes

The central inquiry of this research revolves around the application of energy-efficient structural design principles within the context of airport terminal buildings, which stand as the highest energy consumers within the broader airport complex. A fundamental objective of this study is to discern and elucidate energy efficiency methodologies that can be viably implemented in airport terminal structures, thereby serving as a compendious reference for the formulation of energy-efficient airport terminal designs.

This endeavour seeks to elevate the awareness surrounding the imperative of judicious energy utilization within the precincts of terminal edifices, aspire to unearth the most salient energy efficiency paradigms germane to these buildings, employ exemplary projects and benchmark them against pertinent standards, guidelines, and certification systems, and ultimately distil the findings into an instructive guide that architects and stakeholders can utilize to orchestrate energy-efficient designs or retrofit existing terminals for heightened energy efficiency. Consequently, the sound execution of energy-efficient approaches in terminal buildings, which often involve substantial capital investments, holds the promise of delivering auspicious economic returns and advancing the preservation of our finite natural resources.

This study draws its intellectual underpinnings from an extensive corpus of theses, academic articles, and authoritative guidelines concerning the parameters governing energy-efficient building design. It further takes into account statutory requisites and certification frameworks, airport terminal design strategies, and application modalities, supplemented by an analysis of sample terminal buildings situated across diverse climatic zones. By synergizing the theoretical acumen distilled from the literature review with empirical insights gleaned from energy-efficient practices witnessed in sample terminal structures, this research has meticulously crafted a resourceful guide. This guide, in turn, stands poised to serve as an invaluable compass for architects embarking on the energy-efficient design of airport terminal buildings or contemplating the conversion of extant terminals into exemplars of energy efficiency.

2. LITERATURE REVIEW

The inexorable progression of human history has invariably mirrored advancements within the realm of transportation. In particular, the aviation sector, which burgeoned in the early 20th century, has burgeoned into an indispensable component of contemporary existence. This evolution in air travel has instigated the demand for novel public infrastructure. The pivotal and rudimentary constituents of the aviation domain, known as airports, serve as the nexus wherein aircraft commence and culminate their journeys, ushering passengers and cargo alike into their temporal sanctuaries.

Among the multifarious facets that constitute the aviation landscape, terminal buildings stand as seminal edifices, for they are the linchpin at the ingress and egress of the airport experience. Recent years have witnessed terminal structures being meticulously crafted to serve as bastions where technological advancements harmonize with the burgeoning requisites of passengers. The overarching architectural paradigm has thus transformed, embracing principles of flexibility, innovation, environmental conscientiousness, sustainability, and energy efficiency.

The aviation sector, accounting for 2.2% of the world's energy consumption and responsible for 2% of carbon dioxide emissions, casts a considerable ecological footprint. Within this domain, airports alone contribute 5% of aviation-associated carbon dioxide emissions [14]. Consequently, architects have assumed an augmented mantle of responsibility, tasked with conceiving environmentally responsive edifices within airport precincts. Presently, airport planning is irrevocably intertwined with environmental considerations, motivated in no small part by international aviation bodies and domestic regulatory authorities. Resource efficiency underscores this eco-centric perspective, manifesting through meticulous assessments of airports' long-term ecological impact. Factors encompassing energy consumption, ecological integrity, climate dynamics, land utilization, noise pollution, wastewater management, and the usage of anti-ice agents are meticulously scrutinized [2,15].

Remarkably, an extensive scope exists for heightening airport efficiency through a holistic approach, enabling a 20 to 50% reduction in energy consumption [16]. This imperative is spurred by the stark realization of the substantial energy demands imposed by airports and their resultant environmental adversities. The pursuit of energy efficiency within terminal buildings is progressively championed through novel energy-conservation technologies, the harnessing of renewable energy resources, robust insulation solutions, passive climate regulation mechanisms, and judicious incorporation of natural illumination. These innovations necessitate an innovative reimagining of structural facets encompassing roofs, facades, and foundations within terminal edifices [2].

Airports, as colossal energy consumers, significantly contribute to greenhouse gas emissions, a majority of which stem from fossil-based sources, as depicted in Figure 1. Electricity and fossil fuels, including natural gas, coal, and oil, form the primary energy reservoirs propelling both airside and landside operations. Predominantly, electrical energy takes precedence in sustaining airport operations [2].

In the realm of energy-efficient terminal building design, a dual approach unfolds one involving augmenting energy generation and the other focusing on the amelioration of energy demand. The embrace of active systems assumes a pivotal role in bolstering energy supply, thus mitigating external energy dependence. Diverse systems, including solar, geothermal, wind, and biomass technologies, are amalgamated either singly or in synergy to fulfil the exigencies of heating, cooling, and illumination within airport terminal facilities [17]. Adopting a holistic perspective of renewable energy technologies in tandem with passive systems, integrated seamlessly into the architectural blueprint, represents an indispensable avenue to augment the energy efficiency of terminal structures. Positioning renewable energy systems as integral components of design yields a twofold benefit: it satisfies the energy prerequisites of the edifice with eco-friendly sources, curbing greenhouse gas emissions, diminishing operational costs, and attaining superior energy efficiency.

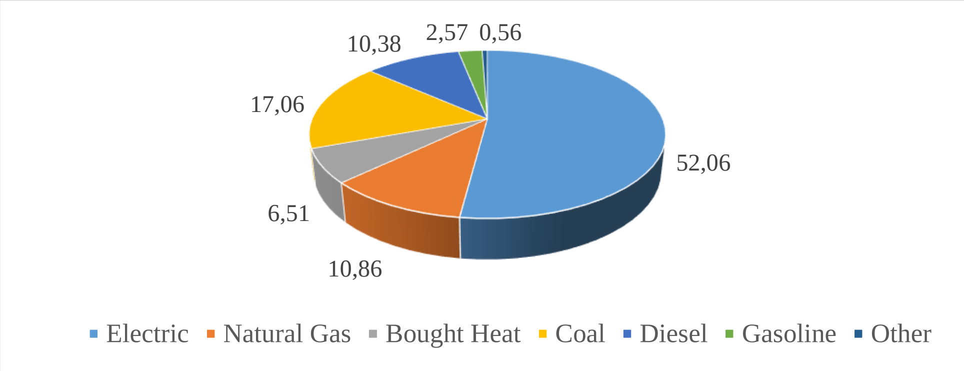

Figure 1. *Energy sources used at airports [3].*

The airside domain of airports encompasses a consortium of energy consumers, notably including radio navigation systems, apron lighting, runway illumination, and auxiliary edifices such as control towers, aircraft maintenance hangars, meteorological stations, and fire station structures. The energy utilization on the airside is demonstrably influenced by crucial factors such as the capacity of aircraft maintenance hangars, the dimensions of the apron area, and the length of illuminated runway and taxiway sections, exerting a significant impact on overall energy consumption [18]. Conversely, on the landside, energy consumption pertains to terminal buildings, cargo terminals, administrative edifices, and vehicular parking zones [19].

Terminal buildings, which play a key role in the transport of passengers and cargo, are the buildings with the highest energy consumption within the airport as shown in Figure 2 [4].

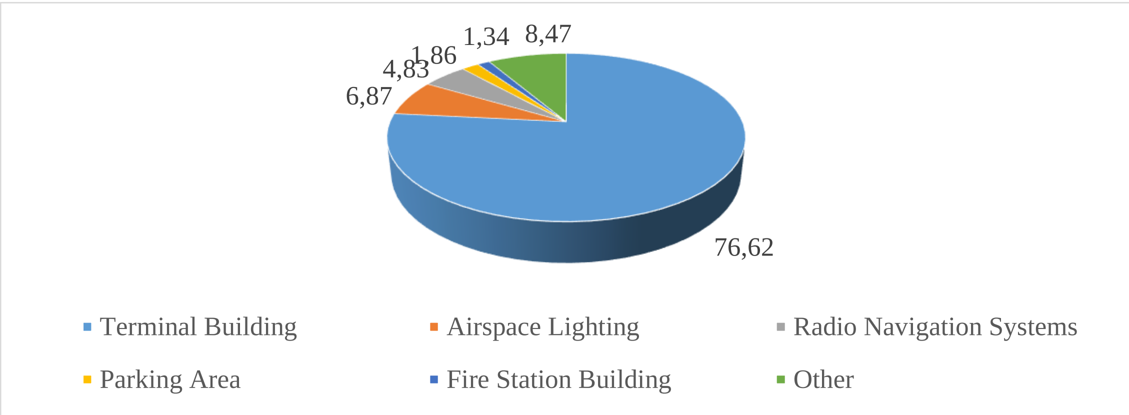

Figure 2. *Energy consumption of a sample airport [4].*

Within terminal buildings, diverse applications engender energy usage, encompassing heating, ventilation, and air conditioning (HVAC) systems, artificial illumination, equipment operation, and hot water provision [20]. HVAC systems, central to fostering indoor comfort conditions, claim the lion's share of energy consumption within terminal structures, as delineated in Figure 3. These systems, constituting over 40% of the electrical energy outlay in airport terminal buildings, nearly monopolize the consumption of natural gas, with the exception of smaller systems dedicated to hot water and culinary purposes [21]. Consequently, the enhancement of HVAC system efficiency, the formulation of strategies to diminish the reliance on HVAC systems, and the tempering of the heating and cooling demands via architectural improvements all feature prominently in the pursuit of energy efficiency.

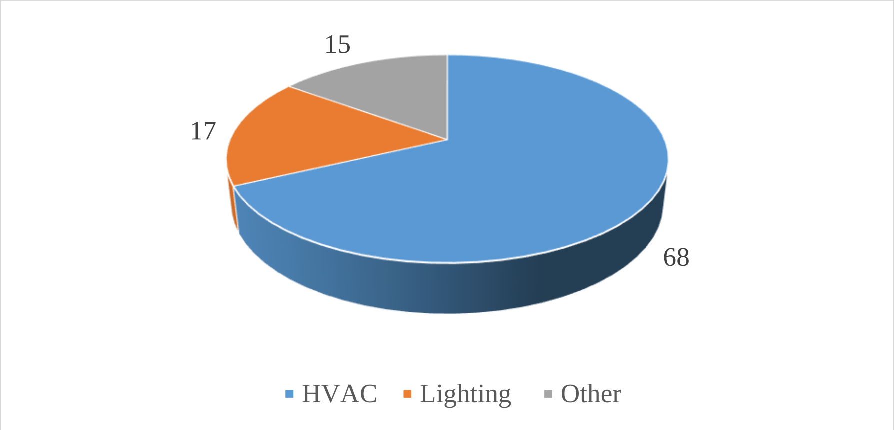

Figure 3. *Energy consumption rates of systems in the terminal building [18].*

The ambit of energy consumption extends to the lighting systems within airport terminal buildings. Given their continuous operation spanning 24 hours daily, lighting systems proffer substantial potential to ameliorate energy efficiency [4]. Methodical planning of lighting systems, integral to the quality of indoor environments and user efficiency, can effectuate reductions in energy consumption while concurrently upholding superior illumination standards. Furthermore, it is imperative to acknowledge that lighting fixtures can induce an auxiliary load on mechanical systems, thus compounding heating-related energy demands [22].

Terminal buildings, characterized by voluminous open layouts, present distinctive challenges with respect to energy consumption, surpassing those encountered by other architectural typologies. Their expansive surface areas amplify thermal exchanges with the external milieu, thereby imposing augmented heating and cooling prerequisites [3]. Notably, the architectural attribute of transparency, pervasive within terminal structures, assumes a pivotal role in energy dynamics. Predominantly, vast glass surfaces, typified by curtain glass facades and roof skylights, constitute substantial segments of the building envelope. Consequently, these glass elements expose the edifice to intense solar radiation, which, in turn, precipitates pronounced elevations in indoor temperatures [4].

In the broader context, it is essential to underscore that the energy footprint of terminal buildings is contingent upon a confluence of factors, including architectural design and the prevailing climatic conditions. Several pivotal parameters exert a salient influence on energy consumption within terminal structures, including but not limited to [22]:

- The dimensions of the terminal building (encompassing the air-conditioned area and surface area interfacing with the external environment)
- Architectural configuration of the terminal building (fragmented or compact)
- Geographic location and prevailing climatic conditions
- Building envelope characteristics and insulation attributes
- HVAC systems specifications
- Harnessing natural daylight for both illumination and winter heating
- Prudent operation of mechanical and electrical systems
- Passenger volume

Indeed, the adept identification of parameters governing a building's energy performance and a nuanced comprehension of its energy consumption characteristics stand as foundational prerequisites for the effective deployment of energy efficiency strategies within the edifice. Incorporating energy consumption data, particularly within high-energy-consuming structures such as airport terminal buildings, as a linchpin during both the revitalization of extant terminal structures and the inception of novel terminal designs, will undeniably be instrumental in fostering energy efficiency within this pivotal segment of infrastructure.

This research endeavours to elucidate the diverse strategies and practices deployed to optimize energy efficiency within terminal buildings. To achieve this objective, a comprehensive analysis of ten airport terminal structures has been meticulously executed. These exemplary terminal buildings span international locations, encompassing Türkiye, the United States, England, Norway, and Ecuador. Notably, a majority of the selected terminal buildings, precisely seven out of ten, have achieved the esteemed LEED (Leadership in Energy and Environmental Design) certification, whereas the remaining three have garnered BREEAM (Building Research Establishment Environmental Assessment Method) certification. These certifications bear testament to their steadfast commitment to sustainable construction practices and ecological responsibility.

A crucial dimension of our analytical framework concerns the diverse climatic contexts in which these terminal buildings are situated. The geographic dispersion underscores the need to consider the impact of climate on energy efficiency initiatives. Within this sample, one terminal building finds itself in the hot-humid climate zone, while the majority, eight in total, are positioned within temperate climate zones. Furthermore, one terminal building operates within a frigid cold climate zone. This strategic selection allows for a nuanced understanding of energy efficiency strategies within varying climatic exigencies.

In pursuit of scholarly rigor and transparency, we have thoughtfully included a comprehensive appendix in this study. This appendix meticulously catalogues detailed information pertaining to each of the ten airport terminal buildings under scrutiny. This inclusion ensures that readers are afforded unbridled access to primary data sources and a thorough comprehension of the architectural intricacies characterizing these exemplar structures.

Although there are differences in energy efficiency practices in the airport terminal buildings analysed within the scope of the study, it is generally seen that certain approaches are adopted. 10 examples of energy efficient practices are categorised in Table 1.

Table 1. *The analysis of energy efficiency practices in existed terminal buildings designed in success on energy efficiency*

ENERGY EFFICIENCY AND GREENHOUSE GAS REDUCTION APPLICATIONS			SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	SAMPLE 6	SAMPLE 7	SAMPLE 8	SAMPLE 9	SAMPLE 10
CLIMATE ZONE*			1A	3C	3A	3B	3B	3B	3B	4A	6A	4A
STRUCTURE SHELL												
ROOF	Thermal insulation applications		O	O	O	O	O	O	O	O	O	
	Roof finishing material colour selection	Light colour roof finishing material	O	O	O	O	O	O	O	O		O
		Dark colour roof finishing material									O	
OPAQUE	External thermal insulation		O	O	O	O		O	O	O	O	

FACADE SURFACES	Facade cladding material colour selection	Light coloured facade cladding material	O	O	O	O	O	O	O	O		O
		Dark coloured facade cladding material									O	
TRANSPARENT FACADE SURFACES	Heat insulated glass and joinery			O	O	O	O	O	O	O	O	
	Solar controlled glass			O	O				O	O		O
BIO-CLIMATIC DESIGN												
	Structure form	Compact form		O	O	O	O	O	O	O	O	O
		Courtyard form	O									
	Solar control	Wide eaves design	O	O		O	O	O	O	O		O
		Sun shading element	O	O	O	O	O	O	O	O		O
	Utilising natural lighting		O	O	O	O	O	O	O	O	O	O
	Utilising natural ventilation		O		O	O	O					
RENEWABLE ENERGY SYSTEMS												
SOLAR ENERGY	Photovoltaic (PV) systems		O	O	O			O	O	O		O
	Solar collectors		O									
	Geothermal heating and cooling systems							O		O	O	
	Snow and ice storage systems										O	
ENERGY SYSTEMS												
	Mechanical ventilation and cooling systems with heat recovery										O	
	Cogeneration systems				O		O					
	Biomass system											O
	Use of energy efficient mechanical equipment		O	O	O	O	O	O	O		O	O
	LED lighting elements		O	O	O	O	O	O	O	O		O
TRANSPORT SYSTEMS												
	Infrastructure for alternative fuelled vehicles			O	O			O				
	Public transport facilities		O	O	O	O	O	O	O	O	O	
	Bicycle paths and parking areas		O		O			O	O			
	Limitation of the car parking area		O	O	O							
AUTOMATION/ CONTROL AND SENSORS												
	Automation/ control and sensors		O	O	O	O	O	O	O	O	O	O
*Climate zone 1A Warm humid climate zone, Climate zone 3A, 3C Temperate humid climate zone, Climate zone 3B Temperate dry climate zone, Climate zone 6A Cold climate zone												

3. METHODOLOGY

In this scholarly pursuit, the overarching objective is the formulation of a design guideline that prioritizes energy-efficient design paradigms. This guideline serves as an instrumental tool to buttress the sustainability endeavours of airport terminal buildings. These structures, owing to their substantial energy consumption and their enduring operational profiles characterized by unique architectural features and operating models, necessitate a meticulous examination within the sustainability discourse.

The empirical foundation of this research was established through a thorough literature review, encompassing both theoretical and practical dimensions. The substantial domain of energy efficiency, being a pivotal component of sustainable design paradigms, served as the focal point for data accumulation. This database was meticulously assembled through an analytical, classificatory, and evaluative process, with a specific focus on energy-efficient building design parameters, relevant legislative requisites, potentials, constraints, and limitations within the context of airport terminal building design methodologies and application modalities, as elucidated in Figure 4.

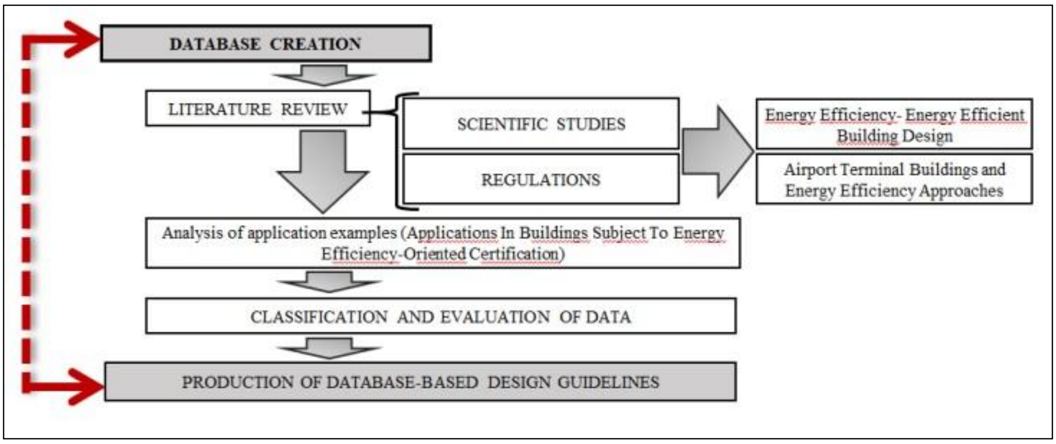

Figure 4. *Creation of the database -Process of producing the design guide*

The data derived for the development of an energy efficiency-oriented sustainable airport terminal building design guide were systematically categorized into eight primary domains. This classification was conducted with due consideration for climate zones, thereby encompassing the evaluative criteria that should be incorporated into the design process, along with their attendant limitations and recommendations. The determination of climate zones and the formulation of solution strategies, contingent upon the requisites of cold (C), temperate humid (TH), temperate dry (TD), hot humid (HH), and hot dry (HD) climate zones, were grounded in the standards delineated in TS 825, which pertains to Türkiye, as delineated in Figure 5.

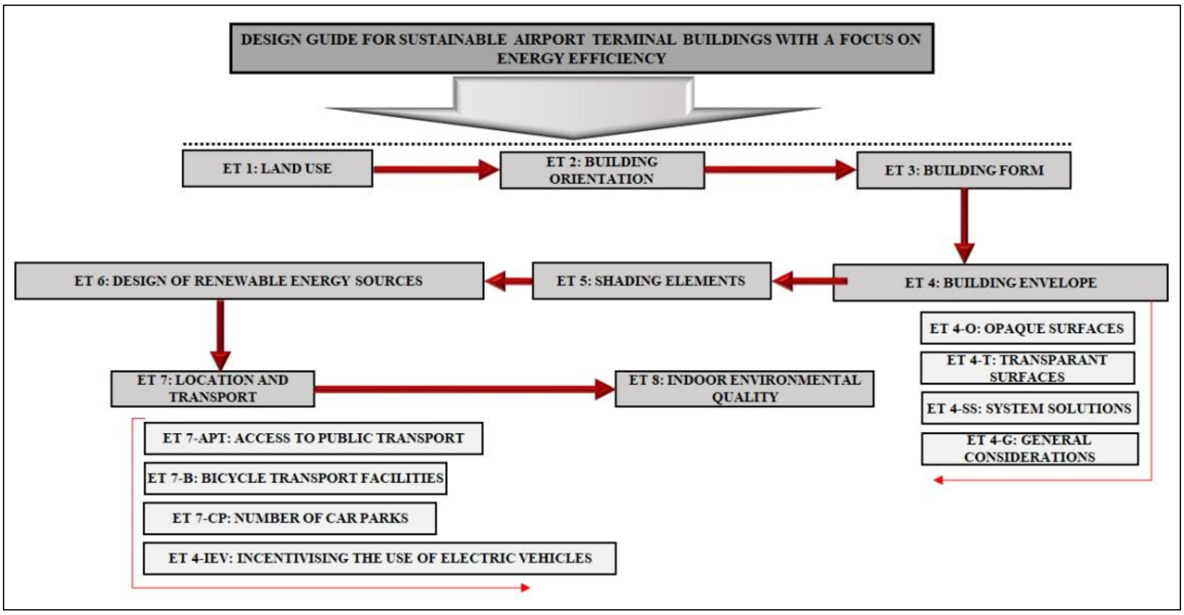

Figure 5. *Energy efficiency orientated sustainable airport terminal building design guidelines evaluation topics (ET)*

Within the guide, emphasis is placed on fostering equilibrium between solid infrastructure and green spaces, a focal facet of the land utilization assessment (Evaluation Topic 1). The subsequent assessment pertains to building orientation (Evaluation Topic 2), wherein judicious orientation selection, contingent upon climate zones, is underscored for optimal efficiency of both active and passive systems. The guide elucidates climatically driven design considerations aimed at reconciling external climatic dynamics with internal climatic conditions and regulating the influence of seasonal climatic variations through building envelope design (Evaluation Topic 3). This leads into a comprehensive exploration of building envelope design (Evaluation Topic 4), a critical determinant of energy efficiency attainment. Herein, opaque, and transparent surface design approaches are tailored to specific climate zone requirements, coupled with proposed system solutions for energy-efficient building design.

Shading element design is the focal point of the fifth assessment (Evaluation Topic 5), followed by the specification of systems conceived to harness renewable energy sources (Evaluation Topic). Topics 7 and 8 delve into location and transportation-related design prerequisites and considerations concerning indoor environmental quality, respectively. The figures (Figure 6-13) accompanying this narrative expound upon the construction of the eight evaluation topics encapsulated within the guide, delineating their sub-components, and elucidating the procedural guidelines to be adhered to by designers.

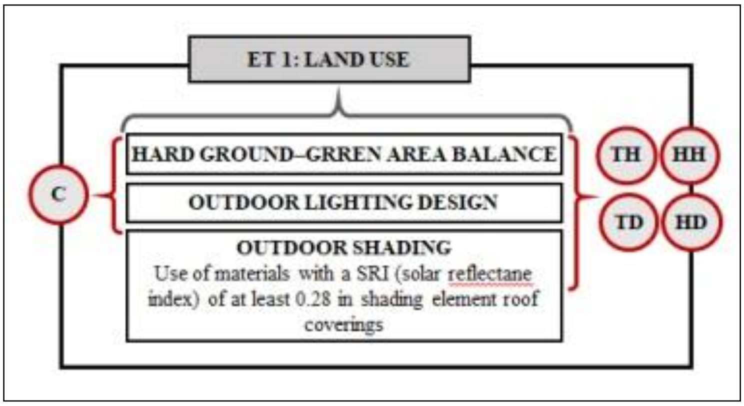

Figure 6. *Design guide evaluation topics 1 (ET1), Land use*

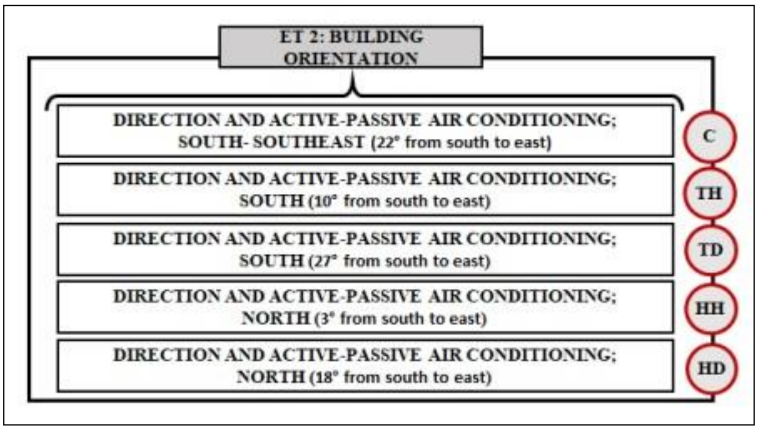

Figure 7. *Design guide evaluation topics 2 (ET2), Building orientation*

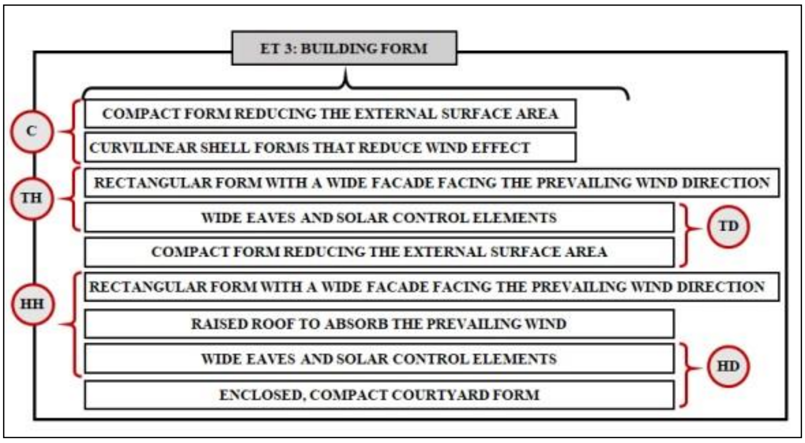

Figure 8. *Design guide evaluation topics 3 (ET3), Building form*

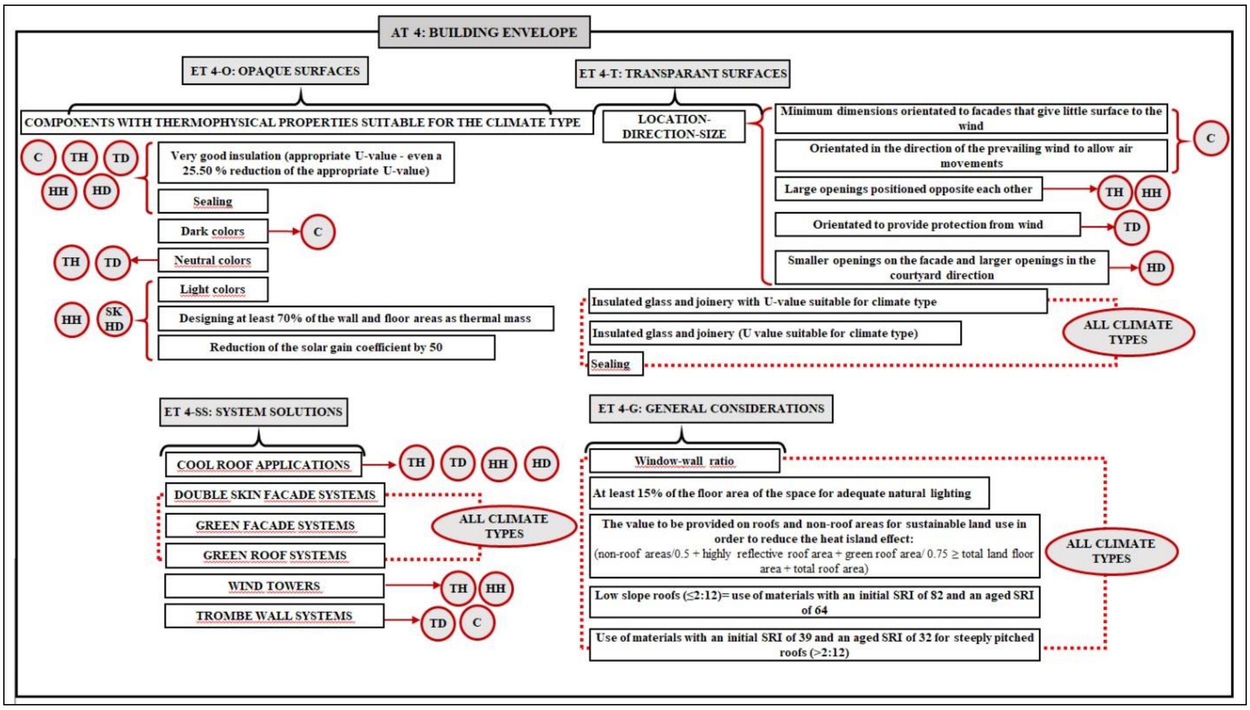

Figure 9. *Design guide evaluation topics 4 (ET4), Building envelope*

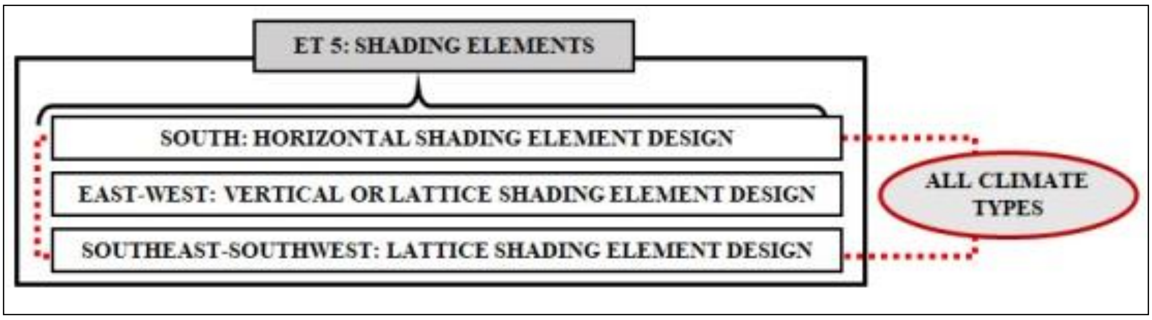

Figure 10. *Design guide evaluation topics 5 (ET5), Shading elements*

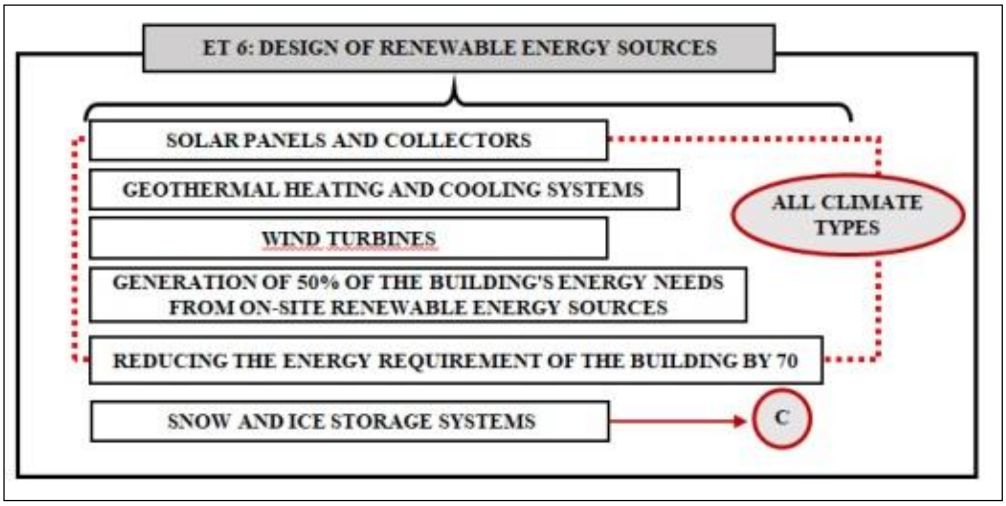

Figure 11. *Design guide evaluation topics 6 (ET6), Design of renewable energy sources*

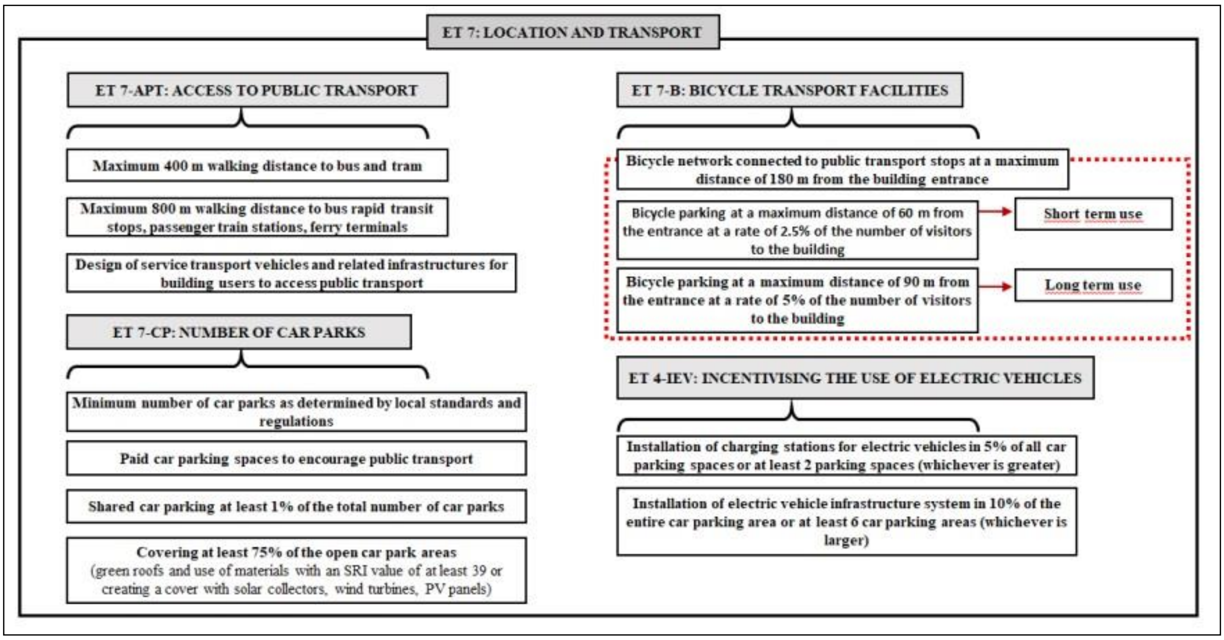

Figure 12. *Design guide evaluation topics 7 (ET7), Location and transport*

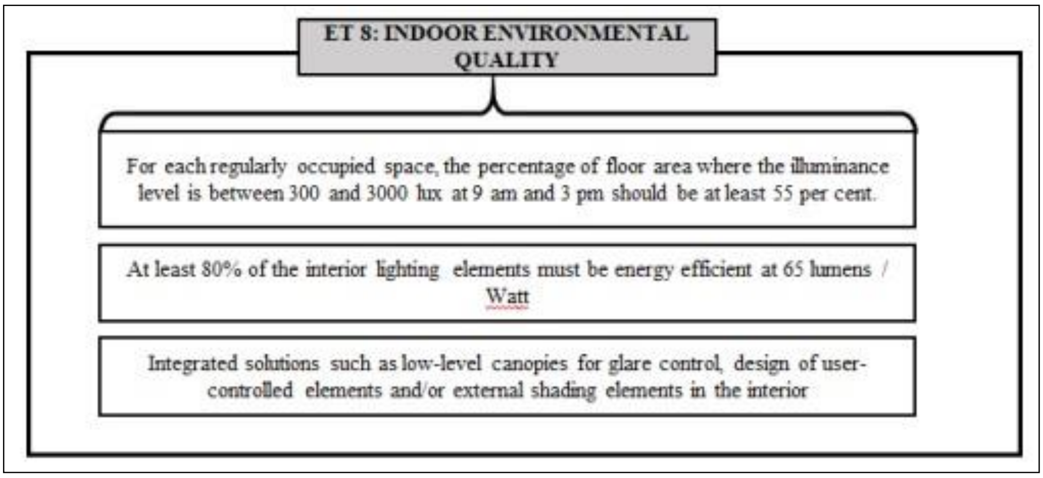

Figure 13. *Design guide evaluation topics 8 (ET8), Indoor environmental quality*

4. CASE STUDY

The Kahramanmaraş Airport terminal building serves as a compelling case study for the meticulous examination outlined in the context of the specialized sustainable airport terminal design guide, with a pronounced focus on energy efficiency. This choice stems from the airport's strategic geographical location, which grants it a pronounced potential for harnessing solar energy resources, and its capacity to engender innovative and energy-efficient architectural solutions, all while judiciously considering pertinent climatic data.

The Kahramanmaraş Airport terminal building finds itself ensconced within the hot-dry climatic zone, a climate typology renowned for its unique challenges and opportunities. Operating at an annual passenger capacity of 2 million travellers, the terminal itself stands as a testament to modern architectural techniques, primarily constructed through the fusion of reinforced concrete and steel construction systems. Comprising a multi-tiered structure, the edifice encompasses a basement floor, ground floor, first floor, and an installation floor, cumulatively offering a generous floor area of 8,730 square meters. The overall closed construction area spans an impressive 22,330 square meters, and it adopts a linear plan scheme, as elucidated in Figure 14 for further clarity.

Figure 14. *Exterior views of the terminal building*

In accordance with its operational nature, a sample terminal building characterized by high energy consumption has been subjected to scrutiny within the framework of the developed design guide. The extent to which climatic data specific to the building's geographic location have been integrated into the design processes is deliberated upon. Subsequently, design strategies oriented toward the enhancement of energy efficiency, guided by the principles articulated in the design guide, are proposed.

5. RESULT AND DISCUSSION

Within the ambit of this research, a prototypical terminal building, characterized by high energy consumption intrinsic to its operational function, has been subjected to comprehensive analysis. This scrutiny aligns with the framework of a meticulously developed design guide. The principal focus of this inquiry is to delineate the extent to which climatic data, specific to the geographic location of the terminal building, have been integrated into the design processes. Subsequently, the guide augments this analysis by proffering strategic design recommendations aimed at ameliorating energy efficiency, within the defined parameters of the guide.

Specifically, the Kahramanmaraş Airport Terminal Building, strategically chosen as a field study within the paradigm of the established method, has undergone meticulous examination with respect to the core evaluation domains and their respective subcategories, as outlined in the design guide. The assessment encompasses the following key domains:
Land Use (ET1): This assessment scrutinizes the extent to which the balance between solid infrastructure and green spaces has been achieved, in alignment with sustainability principles.
Building Orientation (ET2): Here, an appraisal is conducted to ascertain if the building's orientation optimally exploits climatic conditions, thus enhancing energy efficiency.
Building Form (ET3): This evaluation probes the architectural configuration to determine its compatibility with the climatic zone, seeking to minimize energy consumption.
Building Envelope (ET4): This assessment is instrumental in gauging the efficacy of the building envelope in mediating climatic influences and ensuring energy efficiency. It encompasses considerations related to opaque and transparent surface design, specifically tailored to the climate zone's unique exigencies.
Shading Elements (ET5): The design and integration of shading components are scrutinized to ascertain their contribution to energy efficiency, providing insights into potential improvements.
Design of Renewable Energy Sources (ET6): This assessment delves into the incorporation of renewable energy systems within the terminal building's design, seeking to harness sustainable energy sources.
Location and Transportation (ET7): This evaluation assesses the strategic aspects of the building's location and transportation accessibility, considering their implications for energy efficiency.
Indoor Environmental Quality (ET8): The final assessment domain focuses on the indoor environment, exploring design attributes that contribute to superior environmental quality and energy efficiency.
Upon completion of these evaluations, the subsequent phase of this research entails the formulation of recommendations. These suggestions are meticulously designed to address inadequacies and deficiencies identified during the analysis. They are structured to align with the overarching goal of enhancing energy efficiency within the Kahramanmaraş Airport Terminal Building, all within the prescriptive framework of the design guide.

ET1: Land Use

Under the heading of ET1: Land Use, the design guide addresses the balance between solid ground surfaces and green areas, outdoor lighting design, and the design of shading elements in exterior spaces. Upon examination of the Kahramanmaraş Airport Terminal Building, situated in a hot-dry climate zone, it is observed that the surrounding sidewalks, parking areas, and vehicle pathways employ materials characterized by high heat storage capacity and surface reflectivity. Specifically, light-coloured concrete and light gray granite surfacing materials have been utilized. In the context of outdoor lighting design, energy-efficient lighting fixtures have been deployed in the parking area, vehicle pathways, and the V.I.P. section entrance. The expansive entrance canopy of the terminal building has been designed to function as a shading element, while climate-appropriate palm trees have been incorporated into the landscape areas.

Within the purview of the design guide, to attain the recommended balance between solid ground surfaces and green areas, it is advised to employ permeable, porous materials for outdoor surface coverings within the expansive terrain where the existing terminal building stands. The implementation of open-grid system pavement coverings can effectively mitigate the heat island effect associated with solid ground surfaces. Furthermore, the creation of new green spaces and the strategic placement of shade-providing tree species adapted to the hot-dry climate should be prioritized to reduce the heat island effect. In selecting plant species and trees, care should be taken to choose varieties that do not attract wildlife, thereby ensuring aviation safety is not compromised.

Considering the domain of outdoor lighting design, it is imperative that the main entrance of the terminal building be supported by energy-efficient outdoor lighting fixtures. Likewise, the lighting fixtures at public transportation stops should be prominently featured. The design of outdoor lighting should also ensure optimal visual conditions, wayfinding, and environmental perception during periods of insufficient natural daylight. Determining the required lighting intensity to meet safety requirements and strategically positioning light fixtures are essential aspects of the design process. Over-illumination and excessive lighting fixtures should be avoided to prevent light pollution and glare, which could compromise aviation safety. Energy-efficient, cost-effective, non-light-polluting, and low CO2-emitting lighting fixtures should be employed in outdoor lighting design. Automation systems should be deployed to deactivate lighting during non-operational hours, ensuring energy efficiency. When the sample terminal building located in the hot-dry climate zone is evaluated under the heading of outdoor shading elements within the framework of the guideline, it is determined that there are not enough shading elements used outdoors. Shading elements should be utilised to provide shaded areas outdoors. Roof coverings or top surfaces of outdoor shading elements can be covered with materials with an SRI value of at least 0.28 or PV panels. In this way, the newly designed shading elements can be used as a platform for the placement of renewable energy systems by providing a secondary function. It is recommended that the open passenger and personnel car parks of the terminal building should be covered with an upper cover that can be used as a PV panel placement area when necessary, and that materials with an SRI value of at least 39 should be used when selecting the upper cover material.

ET2: Building Orientation

The terminal building's orientation, positioned at a 16° angle to the north based on the layout of the runway and apron, is evaluated under ET2: Building Orientation. This orientation allows for the major transparent surfaces designed on the apron side to face the north, receiving minimal direct sunlight. Thus, the building's alignment effectively avoids the heating effects of the sun, limits the need for climate control, and contributes to energy efficiency in accordance with the primary objective of building orientation in hot-dry climate regions. Figure 15 provides the site layout of the existing terminal building based on bioclimatic data.

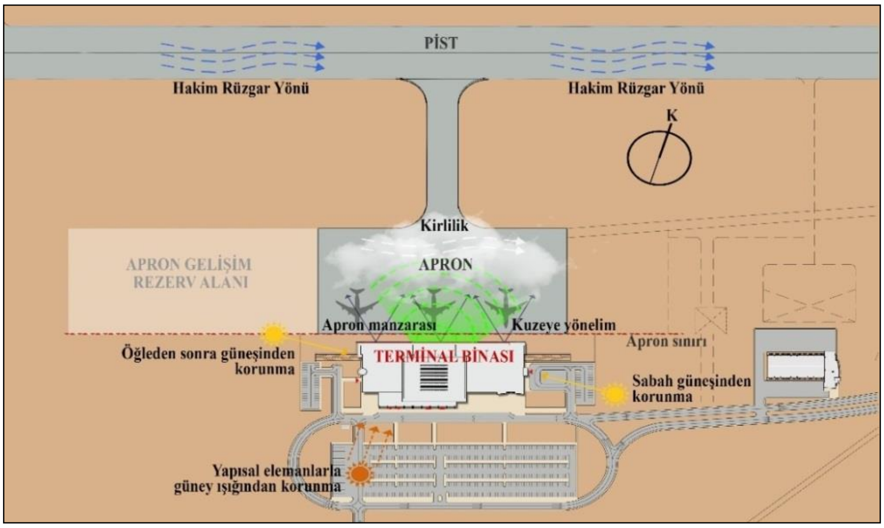

Figure 15. *Terminal building layout according to bioclimatic data*

DK3: Building Form

The sample terminal building exhibits a compact form. Solar control has been achieved through the use of an extensive canopy on the southern facade, creating shaded areas beyond the building's exterior. These shaded areas partially mitigate heat build-up within the building envelope. To reduce undesirable heat gain, the transparency ratio on the southern facade has been intentionally kept lower compared to other sides. The design guide recommends the preference for externally compact courtyard forms in hot-dry climate regions, along with the utilization of extensive canopies and shading elements to facilitate solar control. In the case of the terminal building, the double-height check-in and waiting lounge, which has been designed, can be transformed into a courtyard by creating operable openings in the roof, allowing for cool, shaded areas in the interior and facilitating controlled natural ventilation (Figure 16). This approach can reduce the mechanical cooling loads in a hot-dry climate region with high cooling demands, thereby enhancing energy efficiency. In the interior courtyard, landscape designs featuring region-specific, low-maintenance plants and vertical plant walls can not only create a comfortable and aesthetic environment for passengers but also significantly reduce climate control costs by balancing temperature differentials.

Figure 16. *Conceptual interior courtyard design proposal [25]*

ET4: Building Envelope

Under the heading of ET4: Building Envelope, the guide encompasses opaque surfaces, transparent surfaces, system solutions, and general considerations. Upon scrutiny of the existing terminal building, it is observed that the U-values of opaque components conform to the 2nd Zone standards, while the concrete terrace roof exceeds the specified limit. To align with the U-value stipulated in TS 825 standards, it is recommended to enhance insulation and opt for a 8 cm thick mineral-based stone wool insulation instead of the petroleum-derived XPS material for the concrete terrace roof. The external facade cladding of the building has been selected in compliance with climatic requirements by using light-coloured materials. This choice serves to reflect solar radiation, thereby preventing overheating of the structure and reducing the cooling demand. To ensure energy conservation and establish the desired comfort conditions, it is crucial to implement appropriate detail solutions that prevent thermal bridging and ensure airtightness in the building envelope. In the terminal building, large pine surfaces have been planned on the northern facade, while transparent surfaces on the eastern and western facades, exposed to challenging solar radiation, have been limited compared to the northern facade. The material used for transparent surfaces in the terminal building does not meet the required U-value for the 2nd Zone in the standards. To satisfy the specified U-value in the standard, double glazing with the use of the same glass types and argon gas in the interstitial space is recommended.

The terminal building roof features a cold roof system, as suggested in the guide for hot-dry climate types. This application, particularly effective in hot climate regions, reflects solar radiation during the summer months, reducing the amount of heat transferred to the building and significantly decreasing energy consumption for cooling purposes. The implementation of green roofs, another recommended roof system for hot-dry climate types in the guide, is seen as favourable for enhancing energy efficiency in the sample terminal building. Additionally, green facade systems can be utilized on opaque surfaces of the southern facade of the building to reduce heat absorption. To ensure adequate natural lighting, windows have been designed to comprise 15% of the recommended floor area in the guide. Atriums, gallery voids, roof skylights, and expansive glass surfaces have been employed to support natural lighting. Low-pitched roofs utilize materials with an initial Solar Reflectance Index (SRI) value of at least 82, while steep-pitched roofs use materials with an initial SRI value of at least 39, in line with guide requirements to fulfil performance criteria.

ET5: Shading Elements

In the sample terminal building, solar protection has been accomplished through the utilization of sun-shading elements and canopies. An extensive canopy located on the southern facade of the structure ensures effective solar control. Horizontal sun-shading elements have been employed on the eastern and western facades. Regarding the use of shading elements within the building, it is considered that the implementation of horizontally movable sun-shading elements on the transparent surfaces of the southern facade and vertical sun-shading elements on the eastern and western facades would significantly contribute to mitigating undesirable heat gains from solar radiation and reducing the cooling load of the building (Figures 17 and 18).

Figure 17. *Movable horizontal aluminium sun shading elements proposed to be applied on the south facade of the building [26]*

Figure 18. *Movable vertical aluminium sun shading elements proposed to be applied on the east and west facades of the building [27]*

ET6: Design of Renewable Energy Sources

The province of Kahramanmaraş is situated within the Mediterranean region of Türkiye, known for having one of the highest solar energy potentials. Moreover, it borders the South Anatolian region. Therefore, the terminal building holds significant potential for harnessing solar energy. Currently, solar collectors installed on the terrace roof surface are utilized to meet a certain portion of the hot water demand. In the context of actively harnessing solar energy, the use of photovoltaic panels, which are one of the most preferred systems in terminal buildings, is recommended for the sample terminal building. The approximately 6200 m² flat reinforced concrete terrace roof area and the 720 m² surface area on the southern facade are considered suitable for PV panel installation (Figure 19). Additionally, by covering the south facade's cladding with semi-permeable PV panels, both electrical energies can be generated, and solar protection can be provided (Figure 20).

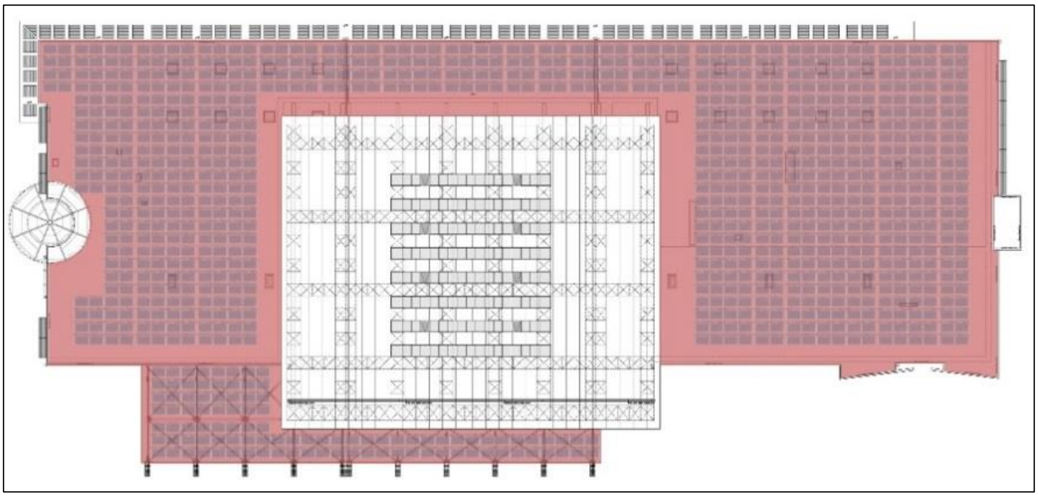

Figure 19. *Suggested area for terminal building PV panel installation*

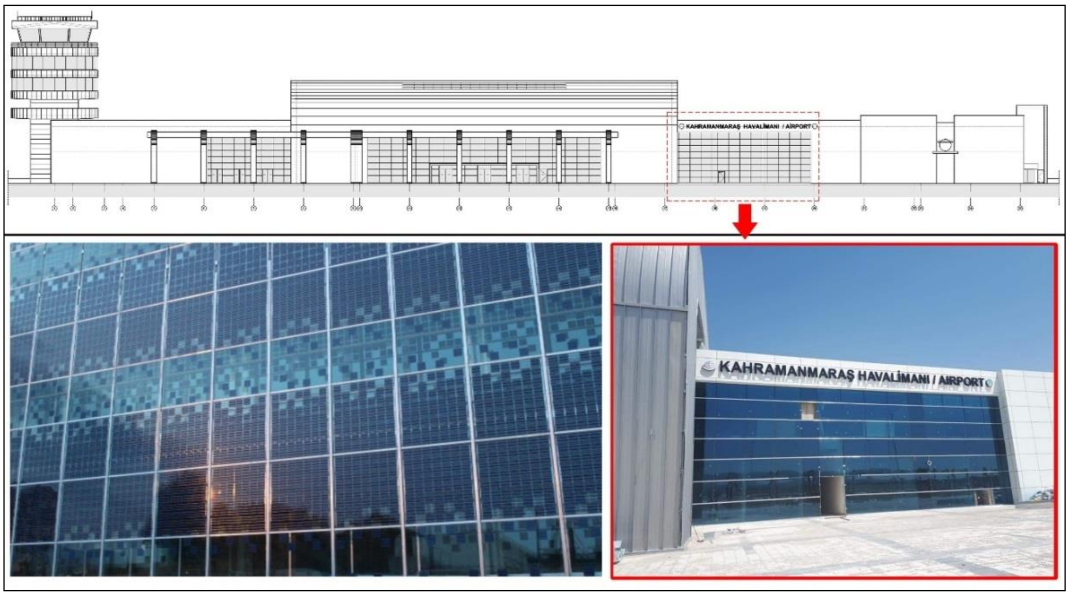

Figure 20. *PV panel system installation proposal on the south facade of the existing building*

ET7: Location and Transportation

Under the ET7: Location and Transportation section of the guide, subheadings encompass access to public transportation services, the number of parking spaces, bicycle transportation opportunities, and the use of electric vehicles. The proximity of the airport to the city centre and its integration with the city's public transportation networks facilitate the access of passengers and personnel to the building. Access to the airport is provided through municipal passenger shuttle buses, city public transportation buses, private shuttle vehicles, taxis, and car rentals. City public transportation buses and airport shuttle vehicles are situated 10 m away from the terminal building's main entrance, on a passenger drop-off and pick-up apron located on the road. The terminal's main entrance canopy defines passenger waiting areas and provides a comfortable and sheltered space for waiting (Figure 21).

Figure 21. *Public transport vehicle stops and sheltered waiting area*

Within the airport premises, there are a total of 430 parking spaces situated above the minimum parking area requirement. It is recommended to reduce the number of parking spaces to meet the requirements and transform surplus parking areas into green spaces. In the newly planned open parking area based on the minimum number, a shared vehicle parking area should be designated, equivalent to 1% of the number of vehicles. Covering approximately 75% of the open parking areas with the recommended overhead structure, made of reflective PV panels, will reduce the heat island effect created by impermeable surfaces near the building and facilitate energy conservation.

Supporting the use of alternative fuel or energy vehicles and bicycle transportation in accessing airports reduces carbon dioxide emissions resulting from conventional fuel vehicle use and provides a more environmentally friendly transportation option. The necessary infrastructure for bicycle access has not been established for reaching the terminal building by bicycle. Within the framework of bicycle transportation opportunities, it is recommended that bicycle transportation networks be planned, connecting to the main entrance of the building, and designed according to the user numbers specified in the guide. For short-term use, four bicycle parking spaces should be located within 60 m of the entrance, and for long-term use, eight bicycle parking spaces should be situated within 90 m of the parking area entrance.

No infrastructure system has been prepared for electric vehicle usage in the terminal building's parking area. Within the guide framework, the proposal suggests that 5% of the entire parking area or a minimum of 2 parking spaces (whichever is larger) should be designated for electric vehicle charging stations. Furthermore, to accommodate future needs, 10% of the entire parking area or a minimum of 6 parking spaces (whichever is larger) should be equipped with an electric vehicle infrastructure system. Accordingly, 15 parking spaces for electric vehicles should be allocated in the terminal building's parking area, with charging stations installed. For future requirements, a suitable infrastructure system should be prepared for up to 30 parking areas.

A proposal site plan has been created considering energy efficiency-focused sustainable airport terminal building design, taking into account the location and transportation evaluation topics (Figure 22). In the proposed site plan, the number of parking spaces has been redesigned according to the minimum requirements and recommended electric vehicle and shared vehicle parking spaces have been designated. Bicycle path and parking area planning have also been undertaken.

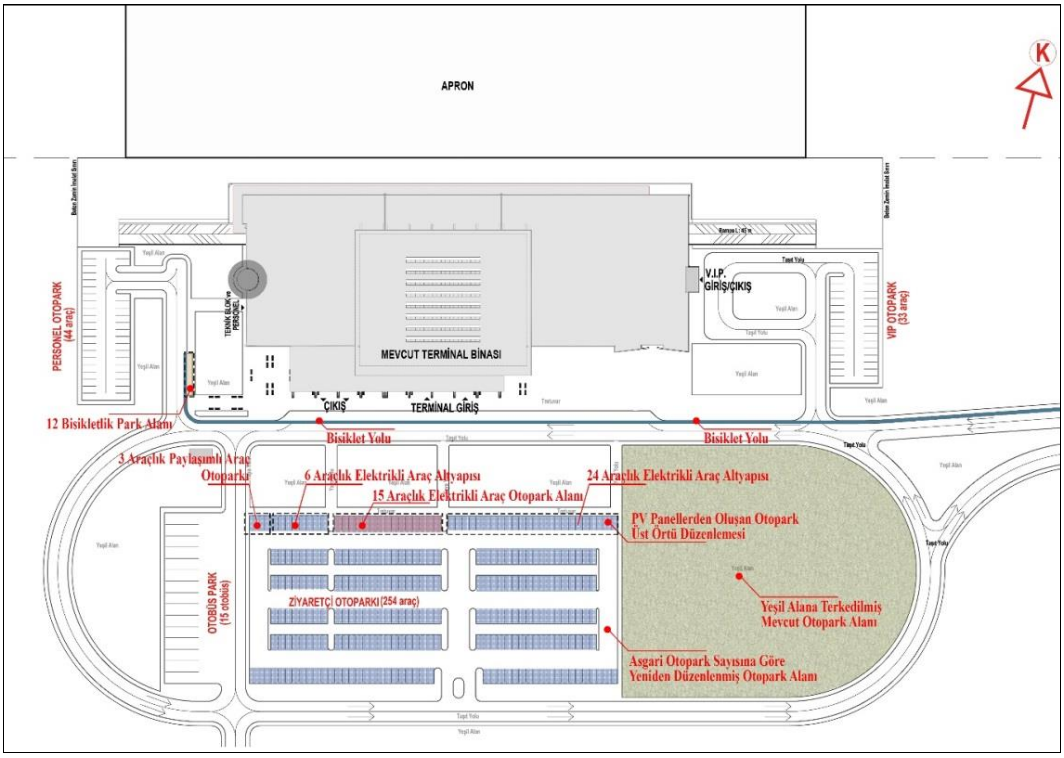

Figure 22. *Proposed site plan study for Kahramanmaraş Airport terminal building*

ET8: Indoor Environmental Quality

Within the framework of the guide, the topic of indoor environmental quality in terminal structures emphasizes the significance of appropriate visual comfort conditions stemming from energy-efficient design and improvements. On the apron facade, which boasts the highest transparency ratio in the terminal building, glare control has been ensured by a 3.50 m-wide steel canopy designed at a lower elevation, thus enhancing the indoor visual conditions. In the central check-in hall of the structure, baffled skylights have been employed for glare control (Figure 23). Energy-efficient LED lighting fixtures have been used for artificial lighting within the building. Motion sensors are installed in all wet areas of the building. In the remaining areas of the building, daylight sensors and motion-sensitive presence sensors are integrated with the ambient lighting levels.

Figure 23. *Indoor glare control solutions*

5. CONCLUSIONS

A substantial portion of energy consumption within terminal buildings is allocated towards the heating, cooling, and ventilation systems, vital for the provision of climatic comfort conditions. Within this context, it becomes readily apparent that the architectural characteristics of terminal buildings, often marked by expansive surface areas, elevate the significance of building envelope design to a paramount level. To ensure energy efficiency in such terminal edifices, a meticulous alignment of the optical and thermophysical attributes of the building envelope with respect to prevailing climatic zones becomes imperative. Mitigating heat transfer between the indoor and outdoor environments, harnessing solar heat gain through the building envelope in an optimized manner, and harmonizing the energy requisites for heating, cooling, and ventilation to achieve equilibrium stand as foundational imperatives in this regard.

It is vital to underscore that the pursuit of energy efficiency in airport terminal buildings should extend beyond the confines of the building itself. Notably, the comprehensive spectrum of energy-efficient design must encompass the meticulous orchestration of the immediate environs and intricacies of transport planning. In tandem with strategic design determinations geared towards energy conservation within terminal buildings, concerted efforts must be undertaken to facilitate energy generation through renewable sources. As contextualized within the ambit of designing an energy-efficient airport terminal building, a salient compendium of practices, as expounded within the energy efficiency-centric sustainable airport terminal building design guide, warrant assiduous consideration.

- Across all climatic zones, it is imperative to select construction materials for the immediate vicinity of structures, particularly terminal buildings, that exhibit properties conducive to reducing the urban heat island effect. Optimal choices involve materials characterized by light colours and high surface reflectance.
- Efficiently balancing hard surface areas with green spaces is critical for sound urban planning. In this regard, minimizing impermeable surface coverage is a fundamental objective.
- To combat the urban heat island effect effectively, prudent application of landscaping and afforestation practices is essential, applicable across all climatic zones. It is of paramount importance to exercise caution in selecting plant species that do not attract wildlife and do not pose aviation safety hazards.
- In regions with hot-humid, hot-arid, temperate-humid, and temperate-arid climates, the incorporation of artificial shading elements is recommended. These shading elements should be fabricated with materials possessing a Solar Reflectance Index (SRI) value of no less than 0.28.
- When designing outdoor lighting systems, careful consideration must be given to determining the appropriate illuminance levels required to meet visual comfort standards, ensure wayfinding capabilities, and address security requisites.
- Energy-efficient and environmentally conscious choices should extend to the selection of outdoor lighting fixtures, emphasizing energy efficiency, minimal light pollution, and low carbon dioxide emissions.
- The implementation of automation systems for outdoor lighting systems should be considered to deactivate lighting during inactive periods, thus reducing energy consumption.
- Orientation of terminal buildings is of utmost significance across different climatic regions. In cold climate zones, terminals should ideally face south, with a deviation of 22 degrees towards the east. In temperate-humid zones, a southern orientation with a 10-degree eastward shift is recommended. For temperate-arid zones, a southern orientation extending 27 degrees eastward is suitable, while in hot-humid climates, a northern orientation with a 3-degree eastward shift is advisable. Finally, in hot-arid regions, a northern orientation with an 18-degree eastward deviation is recommended.
- In cold climate areas, the preference should be for compact and curved building forms that minimize surface area exposed to wind and reduce its impact.
- In temperate-humid zones, selecting rectangular building forms with extensive facade surfaces oriented toward the prevailing wind direction is beneficial. These structures should incorporate broad eaves and sun control elements.

- For temperate-arid regions, compact building forms with corresponding sunshades and sun control elements are advantageous.
- Hot-humid climatic zones should favour building forms that face the prevailing wind direction, thus allowing for natural ventilation. Additionally, these structures should incorporate wide eaves and sun control features into their design.
- Hot-arid climate zones should prioritize compact courtyard-style building forms with integrated sun control designs.
- In terms of building envelope design, it is imperative to implement thermal insulation applications comprehensively, encompassing exterior walls, roofs, foundations, and floor slabs. This insulation should yield appropriate U-values, with an additional emphasis on achieving reductions in U-values ranging from 25% to 50%.
- In the selection of facade colours, neutral tones are recommended for temperate-humid and temperate-arid zones, while dark hues are suitable for cold climate zones. In hot-humid and hot-arid regions, opt for light and reflective colours.
- In hot-humid and hot-arid climates, at least 70% of wall and floor areas should be designed as thermal mass, accompanied by a 50% reduction in solar heat gain coefficient.
- Transparent surfaces in building design should be adapted to specific climatic conditions. In cold climates, minimize the surface area exposed to wind on facades. In temperate-humid and hot-humid climates, opt for larger mutually placed openings. In temperate-arid regions, prioritize wind protection on facades. In hot-arid climates, consider smaller exterior surface openings, but larger openings towards courtyards.
- For temperate-humid, temperate-arid, hot-humid, and hot-arid climatic zones, cold roof applications are beneficial.
- Across all climatic zones, dual-skin facade systems, green facades, and green roof systems should be evaluated for potential incorporation.
- In temperate-humid and hot-humid climatic types, integrating wind towers into the design can mitigate the adverse effects of moisture in the building.
- For cold and temperate-arid climatic regions, trombe wall systems can enhance energy efficiency.
- To ensure sufficient natural lighting, a minimum window area of 15% of the floor area should be incorporated across all climatic zones.
- For low-slope roofs, materials should have an initial Solar Reflectance Index (SRI) of 82 and a weathered SRI of 64. In contrast, steep-slope roofs should utilize materials with an initial SRI of 39 and a weathered SRI of 32.
- To protect against sun exposure, the utilization of solar shading elements is recommended. Horizontal shading elements on the building's southern facade, vertical or lattice shading elements on east-west facades, and lattice-style shading elements on southeast-southwest facades are optimal choices.
- Exploring the renewable energy potential specific to the geographical location of the building is imperative. Incorporating solar panels, collectors, geothermal heating-cooling systems, wind turbines, and snow and ice storage systems into the design can reduce the building's energy requirements by up to 70%, with the additional potential to derive 50% of the building's energy needs from on-site renewable sources.
- Locating terminal buildings in close proximity to accessible public transportation networks is advisable.
- For airports situated on extensive land parcels, the number of parking spaces should align with local standards and regulations, reserving at least 1% of the planned parking spaces for shared vehicle parking areas.
- A minimum of 75% of open parking areas should feature green roofs, upper coverings composed of materials with an SRI value of at least 39, or active systems such as solar collectors, PV panels, wind turbines, and similar technologies.
- To encourage bicycle commuting to terminal buildings, the provision of bicycle lanes and parking facilities is essential.

- Promoting the use of alternative fuel vehicles is recommended within terminal premises. Charging stations for electric vehicles should be installed, accompanied by the requisite infrastructure.

By addressing the design of airport terminal buildings with an approach that covers the applications; less energy and resource consumption, reduced carbon footprint, environmentally sensitive and innovative structures can be obtained.

Drawing upon the sustainable airport terminal building design guide developed in this study, future scientific research endeavours can explore:

- Transforming the approaches outlined in the design guide into legal requirements by aligning them with regulations and civil aviation standards,
- Exploring the potential utilization of the design guide in contemporary digital design approaches, thereby establishing a comprehensive database,
- Evaluating and enhancing the experiences gained from the existing building within the scope of the study for the design of a new airport terminal building.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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ADDENDUMS

Example 1: Galapagos Airport Terminal Building
Example 2: San Francisco International Airport Terminal 2 (Renovation Project)
Example 3: Adnan Menderes Airport Domestic Terminal
Example 4: Los Angeles International Airport Tom Bradley Terminal Building
Example 5: Sacramento International Airport Terminal B
Example 6: San Diego International Airport Terminal 2
Example 7: San Jose International Airport Terminal B
Example 8: London Southend Airport Terminal Building
Example 9: Oslo Airport Additional Terminal Building
Example 10: Heathrow Airport Terminal 2