



**DEVELOPING A COMPARATIVE ASSESSMENT
METHODOLOGY FOR PASSIVE ENERGY
PERFORMANCE IN TURKISH MASS HOUSING
UNDER DIVERSE CLIMATIC CONDITIONS**

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Thesis for the Master's Program in Architecture

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ETHICAL DECLARATION

I hereby declare that I am the sole author of this thesis and that I have conducted my work in accordance with academic rules and ethical behaviour at every stage from the planning of the thesis to its defence. I confirm that I have cited all ideas, information and findings that are not specific to my study, as required by the code of ethical behaviour, and that all statements not cited are my own.

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ABSTRACT

DEVELOPING A COMPARATIVE ASSESSMENT METHODOLOGY FOR PASSIVE ENERGY PERFORMANCE IN TURKISH MASS HOUSING UNDER DIVERSE CLIMATIC CONDITIONS

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This study proposes a mixed-method evaluation workflow designed to assess passive energy design strategies in standardized mass housing. Unlike analyses focused on energy consumption, the study concentrates on how predicted building performance and user-perceived indoor environmental conditions can be jointly evaluated. The aim is to examine the alignment or divergence between modeled assumptions and occupant experiences, enabling a more nuanced assessment of the effectiveness of passive design strategies across different climatic contexts. The proposed workflow is tested through pilot applications in standardized TOKİ housing located in Aydın (hot-arid) and Yozgat (cold-continental), where the building typology remains constant. The methodology integrates quantitative building performance simulations (DA, UDI, UTCI) based on Grasshopper with qualitative data gathered through Post-Occupancy Evaluation (POE) surveys. Findings reveal that similar architectural typologies generate different challenges across climates—for instance, overheating in Aydın and

thermal imbalance in Yozgat. Adaptive user behaviors identified through the surveys—such as closing balconies or using alternative ventilation practices—highlight user practices not fully captured by simulations and underscore the need for multidimensional assessment. Rather than focusing on energy consumption outputs, this study offers an evaluation approach centered on the interaction between simulation results and user perceptions, proposing a method that enables climate- and user-responsive analysis of passive design strategies. While the scope of the study is limited to two regional examples, the presented workflow provides a transferable analytical structure that can support future research and housing design decision-making.

Keywords: Passive Energy Design, Mixed Method Evaluation, Building Performance Simulation, User Experience, Mass Housing.

ÖZET

ÇEŞİTLİ İKLİM KOŞULLARI ALTINDA TÜRK TOPLU KONUTLARINDA PASİF ENERJİ PERFORMANSI İÇİN KARŞILAŞTIRMALI BİR DEĞERLENDİRME METODOLOJİSİNİN GELİŞTİRİLMESİ

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Bu çalışma, standartlaştırılmış toplu konutlarda pasif enerji tasarım stratejilerinin değerlendirilmesine yönelik, nicel bina performans simülasyonları ile nitel kullanıcı geri bildirimlerini sistematik biçimde bir araya getiren karma yöntemli bir değerlendirme iş akışı önermektedir. Çalışma, enerji tüketimi odaklı analizlerden farklı olarak, simülasyonlarla öngörülen performans ile kullanıcılar tarafından algılanan konfor koşulları arasındaki ilişkileri irdeleyerek, bu iki veri kaynağının nasıl birlikte değerlendirilebileceğine odaklanmaktadır. Amaç, modellerde varsayılan koşullar ile kullanıcı deneyimi arasındaki örtüşme veya sapmaları ortaya çıkararak, pasif tasarım stratejilerinin farklı iklimlerdeki etkililiğini daha nüanslı şekilde değerlendirebilmektir. Önerilen iş akışı, Aydın (sıcak-kurak) ve Yozgat (soğuk-karasal) illerinde yer alan, tipolojisi sabit TOKİ konutlarında yürütülen pilot uygulamalarla test edilmiştir. Yöntem, Grasshopper tabanlı nicel bina performans simülasyonlarını (DA, UDI, UTCI) Kullanım Sonrası Değerlendirme (KSD)

anketlerinden elde edilen nitel verilerle entegre etmektedir. Elde edilen bulgular, benzer mimari yapıların farklı iklimlerde farklı zorluklar ürettiğini göstermekte; örneğin Aydın'da aşırı ısınma, Yozgat'ta ise ısıl dengesizlik gibi sorunlar ortaya çıkmaktadır. Anketler aracılığıyla belirlenen uyumlayıcı kullanıcı davranışları (örneğin balkon kapatma, alternatif havalandırma yöntemleri), simülasyonların yakalayamadığı kullanıcı pratiklerine işaret ederek, çok boyutlu değerlendirme ihtiyacını ortaya koymaktadır. Bu çalışma, enerji tüketim çıktılarından ziyade, simülasyonlar ve kullanıcı algıları arasındaki etkileşime odaklanan bir değerlendirme yaklaşımı sunmakta; bu yönüyle, pasif tasarım stratejilerinin iklime ve kullanıcı deneyimine duyarlı biçimde analiz edilebilmesi için kullanılabilir bir yöntem önermektedir. Her ne kadar çalışma kapsamı iki örnek bölge ile sınırlı olsa da, sunulan iş akışı, gelecekteki araştırmalar ve konut tasarım kararları için aktarılabilir nitelikte bir değerlendirme çerçevesi sağlamaktadır.

Anahtar Kelimeler: Pasif Enerji Tasarımı, Karma Yöntem, Bina Performans Simülasyonu, Kullanıcı Deneyimi, Toplu Konut.

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TABLE OF CONTENTS

ABSTRACT.....	iv
ÖZET.....	vi
ACKNOWLEDGEMENTS.....	viii
TABLE OF CONTENTS.....	ix
LIST OF TABLES.....	xiii
LIST OF FIGURES.....	xiv
CHAPTER 1: INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement	2
1.3 Research Purpose	3
1.4 Research Questions.....	5
1.5 Research Methodology and Design	5
1.6 Research Outline.....	7
CHAPTER 2: PASSIVE ENERGY DESIGN IN TÜRKİYE	9
2.1. Climate Related Data.....	9
2.2. Building Shape and Orientation	10
2.3. Thermal Mass	11
2.4. Thermal Insulation.....	12
2.5. Window Design and Glazing	13
2.6. Shading Elements.....	14
CHAPTER 3: MASS HOUSING IN TÜRKİYE.....	16
3.1. Mass Housing	16
3.2. Development of Mass Housing Production in Türkiye.....	16
3.3. TOKİ	17
3.3.1. Historical Development and Institutional Role.....	17
3.3.2. TOKİ Housing Typologies and Apartment Layouts	19
3.3.3. Common Construction Materials and Building Envelope Features	21

3.3.4. Design Approach in Different Climatic Zones.....	21
CHAPTER 4: CASE STUDIES: COMPARATIVE ANALYSIS OF TOKİ HOUSING IN TWO CLIMATIC ZONES OF TÜRKİYE	23
4.1. Climatic Assessment of Aydın & Yozgat	23
4.2. Building Typology and Construction Characteristics of Aydın & Yozgat...	27
4.3. Evaluation of the Selected TOKİ Housings in Aydın & Yozgat	28
4.3.1. Location and Site Context	28
4.3.2. Orientation and Plan Typology.....	29
4.3.3. Material and Building Envelope Properties	32
CHAPTER 5: SURVEY	37
5.1. Survey Design and Methodology	37
5.1.1. Aim and Rationale.....	37
5.1.2. Target Participants and Demographics.....	37
5.1.3. Survey Content	38
5.1.4. Implementation Process	39
5.2. Survey Results	40
5.2.1. Thermal Comfort.....	41
5.2.2. Visual Comfort & Daylight Perception	43
5.2.3. Indoor Air Quality & Ventilation	44
5.2.4. Material Performance & Building Envelope	45
5.2.5. Comparative Evaluation of Survey Results.....	46
CHAPTER 6: SIMULATION STUDY	48
6.1. Methodology and Modeling Assumptions.....	48
6.1.1 Building Energy Simulation	48
6.1.2 Simulation Approach and Tools.....	49
6.1.3 Base Case Model Parameters	50
6.1.4. Evaluation Metrics and Performance Criteria	54

6.2. Daylight Simulation Results.....	56
6.2.1. Annual Daylight Autonomy (DA) Analysis	56
6.2.2. Seasonal Daylight Autonomy (DA) Analysis.....	58
6.3. Thermal Comfort Simulation Results.....	63
6.3.1. Annual Thermal Comfort (UTCI) Analysis	63
6.3.2. Seasonal Thermal Comfort (UTCI) Analysis	65
6.4. Comparative Evaluation of Simulation Results	68
CHAPTER 7: DISCUSSION	70
7.1. Integrated Evaluation of User Experience and Simulation Results	70
7.1.1. Thermal Comfort.....	70
7.1.2. Visual Comfort & Daylight Perception	72
7.1.3. Indoor Air Quality & Ventilation.....	73
7.1.4. Material Performance & Building Envelope	74
7.2. Evaluation of Climate-Responsive Design Strategies in Mass Housing	76
CHAPTER 8: CONCLUSION.....	78
8.1. Summary of Findings	78
8.2. Limitations of Study	79
8.3. Potential Directions for Future Research	80
REFERENCES.....	82
APPENDICES	86
APPENDIX A – Revised Climate Zoning in Türkiye (TS 825 – 2025 Update) ..	86
APPENDIX B - Distribution of TOKİ Projects by Province	89
APPENDIX C – Visual Documentation of Selected TOKİ Projects.....	90
APPENDIX D – Construction Details of Building Envelope Elements.....	92
APPENDIX E – Survey Questionnaire & Answers	96
APPENDIX F - Simulation Input Parameters	101
APPENDIX G - Useful Daylight Illuminance (UDI) Distribution	103

APPENDIX H - Ethical Board Approval..... 105



LIST OF TABLES

Table 1. Building Materials & Envelope Properties in Aydın/ Yozgat TOKI Buildings.....	35
Table 2. Geometric characteristics of the standardized base case model.....	52
Table 3. Color scale interpretation and performance criteria for Annual Daylight Analysis.....	58
Table 4. Color scale interpretation and performance criteria for Summer DA Daylight Illuminance (DA) Analysis.....	60
Table 5. Color scale interpretation and performance criteria for winter DA Analysis.....	62
Table 6. Comparison of Simulation Results and Survey Feedback.....	75

LIST OF FIGURES

Figure 1. Climate regions according to Turkish building code (Source: TS825, 2013).	10
Figure 2. Building Shape and Orientations by different climatic zones in Türkiye. (Source: Zeren, 1987).....	11
Figure 3. Thermal mass properties in TS 825 (Source: Makina Mühendisleri Odası, 2025).....	12
Figure 4. Energy properties of glass in TS 825 (Source: Makina Mühendisleri Odası, 2025).....	14
Figure 5. Geographical distribution of TOKI housing projects in Türkiye (Based on data from TOKI, "Projects by Province").	18
Figure 6. Floor Plan of Afyon (a), Balıkesir (b) and Nevşehir (c) TOKİ Houses	20
Figure 7. Temperature Range Diagram of Aydın & Yozgat (Data Source: Climate Consultant).	23
Figure 8. Radiation Range Diagram of Aydın & Yozgat (Source: Climate Consultant)	24
Figure 9. Sun Shading Chart of Aydın & Yozgat (Source: Climate Consultant)	25
Figure 10. Psychrometric Chart of Aydın & Yozgat (Source: Climate Consultant) .	26
Figure 11. Aydın TOKI Housing Complex, 2+1 Floor Plan (Source: Aydın, TOKI)	30
Figure 12. Aydın TOKI Housing Complex, 3+1 Floor Plan (Source: Aydın, TOKI)	31
Figure 13. Yozgat TOKI Housing Complex, 2+1 Floor Plan (Source: Yozgat, TOKI)	31
Figure 14. North-South Elevation Drawing, East-West Elevation Drawing of Aydın TOKI Building	34
Figure 15. North-South Elevation Drawing, East-West Elevation Drawing of Yozgat TOKI Building	34
Figure 16. Context site model of the Aydın TOKİ settlement, illustrating the 5-story reference block and the surrounding shading obstacles (7 blocks).	53
Figure 17. Context site model of the Yozgat TOKİ settlement, illustrating the 5-story reference block and the surrounding shading obstacles (6 blocks).	53

Figure 18. Annual Daylight Autonomy (DA) distribution analysis of the Aydın (a) & Yozgat (b) floor plans of reference blocks.	57
Figure 19. Seasonal (summer) Daylight Autonomy (DA) distribution analysis of the Aydın (a) and Yozgat (b) floor plans of reference blocks.	59
Figure 20. Seasonal (winter) Daylight Autonomy (DA) distribution analysis of the Aydın (a) and Yozgat (b) floor plans of reference blocks.	62
Figure 21. Annual Universal Thermal Climate Index (UTCI) distribution analysis of the Aydın (a) and Yozgat (b) floor plans of reference blocks.	64
Figure 22. Seasonal (summer) Universal Thermal Climate Index (UTCI) distribution analysis of the Aydın (a) and Yozgat (b) floor plans of reference blocks.	65
Figure 23. Seasonal (winter) Universal Thermal Climate Index (UTCI) distribution analysis of the Aydın (a) and Yozgat (b) floor plans of reference blocks.	67

CHAPTER 1: INTRODUCTION

1.1 Background

In modern architecture, sustainable design has evolved from a theoretical preference into a central necessity, serving as a critical response to the escalating energy demands of the built environment (Sev, 2009). As indicated by Yeang (2012), approximately two-thirds (65%) of a building's total lifecycle energy consumption occurs solely during its operational phase. Since the rapid acceleration of housing production, driven by population growth, further exacerbates this environmental burden, the implementation of energy-efficient design strategies has become of critical importance in current practice (Bilgili, 2023). To mitigate the reliance on mechanical conditioning systems—a primary driver of high energy consumption in the residential sector—it is essential to supplement these systems with passive design principles. Defined as a process that utilizes natural energy sources and climatic data to optimize the thermal balance of a building, passive energy design plays a pivotal role. In this context, the integration of these strategies during the initial design phases is vital for ensuring the structure's overall energy performance and sustainability (Berköz et al., 1995)

Erol and Unal (2015) emphasize that the construction sector of Türkiye is a major driver of the national economy, contributing 6.6% to real GDP growth. The residential and service sectors collectively account for approximately 35% of Türkiye's final energy consumption (EUROSTAT, 2016). Given the ongoing expansion in the building sector, this share is expected to increase, necessitating a focus on energy-efficient design solutions.

In response to the growing housing demand in Türkiye, an Urgent Action Plan was implemented in January 2003, accelerating mass housing and urban transformation initiatives across the country. Housing Development Administration of the Republic of Türkiye (TOKİ) was designated to lead this process, and its institutional framework was consequently reinforced, alongside an expansion of its administrative authorities. Since then, TOKİ has pursued a wide range of objectives, including regulating the housing market through structured and innovative production models, mitigating speculative trends by emphasizing quality, durability, and affordability, and

contributing to a more balanced spatial distribution of the population throughout the national territory (Housing Development Administration of the Republic of Türkiye).

Although meeting standards of insulation and earthquake safety, TOKİ projects often do not use the full potential of energy effectiveness (Karaca & Varol, 2012). Turkish Standard TS 825 establishes guidelines for building insulation and divides the country into four climate zones, each with designated U-values for different building components (Erdogdu, 2010). However, even within the same climatic region, variations in building orientation, location, and urban layout affect energy savings potential, necessitating a more tailored approach to energy-efficient design.

1.2 Problem Statement

Passive design strategies significantly reduce dependence on mechanical heating and cooling systems (Cole, 2016). This is particularly important for countries like Türkiye, where increasing energy demands coincide with a heavy reliance on energy imports. Given that approximately 80% of residential energy consumption in Türkiye is allocated to heating and cooling, the implementation of passive energy solutions and insulation technologies offers a cost-effective and sustainable alternative to conventional energy procurement.

The rapid pace of urbanization and the expansion of mass housing projects—especially those initiated by the Housing Development Administration of the Republic of Türkiye (TOKİ)—intensify the demand for energy-efficient architectural solutions. While these developments comply with basic regulations for insulation and seismic safety, studies indicate that they fall short in maximizing their energy-saving potential (Karaca & Varol, 2012).

A fundamental prerequisite for energy-efficient residential architecture is the calibration of passive strategies—including natural ventilation, insulation, and solar control—to local meteorological contexts. However, a significant disconnect exists between Türkiye's diverse climatic reality and its regulatory framework. As noted by Madarati (2021), current national codes tend to enforce static thermal performance standards regardless of regional disparities; for instance, identical fenestration units (U-values) are legally permissible in vastly different temperature zones. This lack of

regulatory sensitivity to local climate dynamics creates a standardized approach that severely limits the potential and efficacy of passive design principles, particularly in regions characterized by extreme weather conditions.

Existing researches confirm that adapting building envelopes to local climatic conditions is highly effective. For example, Schimschar et al. (2016) demonstrated across twelve Turkish cities that climate-responsive insulation and window selection significantly lower energy demand. Similarly, existing studies specifically on mass housing have utilized comparative simulations to optimize performance; Bilgili (2023) examined natural ventilation methods in TOKİ settlements, while Madarati (2021) focused on energy efficiency proposals for horizontal architecture using BIM.

Among the studies addressing performance in standardized social housing, the work of Harputlugil et al. (2019) is particularly noteworthy. Their research analyzes how occupant behavior—such as window use, curtain selection, and occupancy timing—affects annual energy consumption and thermal comfort in TOKİ dwellings located in four different climate zones. Through quantitative simulations and sensitivity analysis, they classify behavioral profiles and assess their influence on energy performance, ultimately presenting a decision-support tool tailored to these findings. The study prioritizes energy consumption as its main evaluation criterion and examines how user behavior modulates building energy use under standard design conditions.

These studies reflect an increasing awareness that the performance of standardized housing cannot be fully understood through design parameters or climate responsiveness alone. Rather, building operation and occupant behavior introduce further complexity in evaluating how well passive strategies function across differing environments. This evolving discourse opens space for alternative approaches that consider not only modeled energy use, but also how environmental conditions are experienced, perceived, and adapted to by users.

1.3 Research Purpose

Unlike previous studies that model occupant behavior to quantify its impact on energy consumption—such as Harputlugil et al. (2019), which prioritizes behavioral sensitivity within energy performance metrics—this study focuses on the development

of an emerging methodological approach. The primary purpose is to propose and implement a mixed-method evaluation workflow that integrates simulation-based predictions with post-occupancy user feedback, aiming to assess the contextual validity of passive design strategies in standardized mass housing.

Rather than seeking to generalize performance outcomes or measure user-driven energy variation, this research explores how simulated performance metrics—such as daylight availability and thermal comfort indices (DA, UDI, UTCI)—correspond with users’ reported indoor experiences, including perceptions of comfort, light, ventilation, and material effectiveness.

The proposed workflow functions as a diagnostic framework, intended to reveal areas of alignment, divergence, or ambiguity between design assumptions and actual occupant experience. It emphasizes interpretive depth over quantification, and situates user insight as an active component of performance assessment.

To test this workflow, the study applies it to two climatically distinct regions in Türkiye—Aydın and Yozgat—using identical TOKİ housing typologies as pilot cases. The approach combines parametric performance simulations with post-occupancy evaluation (POE) surveys.

The evaluation framework concentrates on a set of architectural parameters that critically shape passive energy performance:

- Building Orientation
- Insulation
- Window Design and Glazing
- Shading Elements
- Thermal Mass
- Natural Ventilation
- Building Materials
- Roof Design
- Lighting
- Landscaping

While not all parameters are analyzed in equal depth within the scope of this study, their collective influence forms the basis of passive energy strategy. Rather than

isolating individual variables, the research considers how these elements interact as part of an integrated system, evaluated through both modeled outputs and lived user experience. Through this context-aware and multi-perspective approach, the study contributes a methodological tool for evaluating standardized housing typologies under varying climatic conditions, with potential application to future passive design research and policy development.

1.4 Research Questions

The research aims to address the following primary question:

How can a mixed-method evaluation workflow be structured and applied to diagnose the climatic adequacy of passive design strategies in standardized mass housing typologies across contrasting climatic zones in Türkiye?

This question is central to establishing a transferable framework for understanding how standardized designs perform in Türkiye's diverse climate zones. By addressing this question, the study seeks to demonstrate a comprehensive analytical approach that identifies the strengths and limitations of mass housing implementations.

To provide a comprehensive answer to the main question and test the proposed workflow, the study investigates the following sub-questions through pilot case studies:

What does the application of the proposed evaluation workflow to two climatically contrasting pilot cases (Aydın and Yozgat) reveal about the responsiveness of TOKİ's standardized architectural typology to differing environmental demands?

How does the integration of quantitative simulation outputs and qualitative user feedback contribute to identifying divergences between predicted building performance and occupant-perceived comfort?

1.5 Research Methodology and Design

This research employs a mixed-method approach combining qualitative and quantitative techniques to propose and test an evaluation workflow for assessing

passive design strategies in standardized mass housing. Rather than limiting the scope to a static performance assessment, the methodology is structured as a transferable analytical framework that integrates user surveys and simulation studies to examine how building performance is perceived and modeled across contrasting climatic zones.

The research process is organized into three primary phases:

The first phase involves an extensive review of national and international literature on passive design strategies, energy-efficient housing, and climate-responsive architecture to inform the conceptual foundation of the evaluation workflow. In parallel, Türkiye's building energy performance standards and insulation regulations are examined to define the legal and technical context. Additionally, the development, housing typologies, and construction characteristics of TOKİ projects are analyzed to understand their design logic and implementation patterns, serving as the baseline for the proposed assessment model.

In the second phase, the proposed methodology is applied to two pilot case studies selected to represent contrasting climatic conditions: a TOKİ settlement in Aydın (Hot–Humid) and one in Yozgat (Cold–Continental). Architectural plans, facades, and envelope details of these representative test cases are comparatively analyzed to identify the extent of passive design integration. To support the user-centered dimension of the workflow, a survey study is conducted with residents to assess user satisfaction, comfort perception, and awareness of passive design features. This combination of technical and experiential data provides grounding for the qualitative layer of the proposed method.

The third phase focuses on simulation-based exploration of environmental performance. Using computational tools such as Grasshopper, thermal performance and daylight availability are simulated for both pilot cases. These simulation outputs are then compared with survey results to examine the degree of alignment or divergence between design characteristics and perceived comfort.

By combining these three methodological components—contextual review, survey-based user insight, and simulation-driven performance modeling—this study proposes a structured evaluation workflow. Aydın and Yozgat were selected as case studies due to their sharply contrasting climatic profiles and the availability of standardized TOKİ

typologies, enabling environmental variation to be tested while maintaining architectural consistency.

The application of this workflow to two pilot cases does not aim to produce nationally representative conclusions. Rather, it serves to illustrate the internal logic and practical feasibility of the evaluation framework within a controlled research context. The findings should be interpreted as indicative of the workflow's diagnostic value, particularly in relation to integrating user experience with performance prediction in mass housing environments.

1.6 Research Outline

As previously discussed, this thesis is structured to develop and apply a climate-responsive evaluation workflow for mass housing in Türkiye. Using standardized TOKİ projects as representative test cases, the research explores the application of this mixed-method framework across different climatic regions. The study is divided into eight main chapters:

Chapter 1 introduces the research problem, establishing the aim, scope, and significance of the study. It defines the necessity of a structured evaluation methodology and outlines the limitations of the research, explicitly framing the selected case studies as pilot applications within a broader analytical context.

Chapter 2 establishes the theoretical framework by critically examining passive design strategies specifically within the Turkish context. This chapter focuses on the evolution of national energy regulations (TS 825), the transition from traditional vernacular architecture to modern reinforced concrete systems, and the current material practices in the construction sector.

Chapter 3 provides the macro-context of the study. It examines the historical development, organizational structure, and standardized construction practices of the Housing Development Administration (TOKİ), setting the stage for the specific pilot applications.

Chapter 4 presents a detailed technical analysis of the selected test areas: Aydın (Hot-Dry) and Yozgat (Cold-Continental). This chapter comprehensively documents the

specific climatic conditions, architectural typologies (plan schemes), building envelope characteristics, and material specifications of the examined housing units.

Chapter 5 constitutes the user-centered validation phase of the workflow. It analyzes the qualitative data obtained from field surveys, investigating the occupants' demographic profiles, their declared thermal and visual comfort perceptions, and their behavioral adaptations in response to the indoor environment.

Chapter 6 presents the quantitative verification phase derived from thermal simulations. It evaluates the base-case performance of the housing units in terms of heating/cooling loads and adaptive comfort metrics, highlighting the physical performance differences between the two climatic zones.

Chapter 7 serves as the 'Discussion' section, presenting an integrated evaluation of user experience and simulation results. This chapter synthesizes the subjective data drawn from user feedback (Chapter 5) with the objective findings of the building performance simulations (Chapter 6). Rather than focusing solely on discrepancies, the analysis highlights areas where theoretical models align with real-world feedback, while also identifying patterns of divergence between simulation assumptions and user-reported comfort.

Chapter 8 concludes the study by summarizing the applicability of the proposed evaluation framework. It revisits the initial research questions, acknowledges the limitations of the pilot study, and outlines directions for future research—particularly emphasizing the potential transferability of the workflow to broader multi-region housing evaluations.

CHAPTER 2: PASSIVE ENERGY DESIGN IN TÜRKİYE

Passive design strategies constitute a fundamental component of building energy performance, relying primarily on the effective management of solar radiation and natural ventilation. The application of these principles varies significantly according to climatic priorities. In hot climate zones, the primary objective is cooling; this is achieved by minimizing thermal loads through shading elements—such as overhangs, vegetation, or louvers—and utilizing natural airflow. Additionally, the use of thermal mass plays a critical role in these regions by absorbing excess heat during the day and releasing it gradually at night, thereby stabilizing indoor temperatures (Gallo, 1998).

2.1. Climate Related Data

Türkiye, located between 36°–42° North latitude and 26°–45° East longitude, acts as a physical and climatic bridge between Europe and Asia. Due to its unique topography, the country exhibits significant climatic diversity, generally characterized by three main zones: the temperate and rainy Black Sea region; the hot-dry Mediterranean coastline; and the continental interior marked by cold, snowy winters and dry summers (Esiyok, 2006).

Various scientific studies have been conducted to categorize this climatic complexity. The Köppen climate classification, originally introduced in 1834 and later refined into the global Köppen-Geiger system (1954), serves as a primary foundation. Based on this system, Yılmaz (2018) identified 13 distinct climate zones within Türkiye using monthly average temperature and precipitation data. Similarly, Öztürk, Çetinkaya, and Aydın (2017) analyzed data from 512 meteorological stations and classified the country into 10 sub-climate types under three main categories. Furthermore, recent studies focusing on thermoeconomic analysis have proposed the addition of a fifth climatic zone to optimize building thermal regulations.

From a regulatory perspective, the standard for thermal insulation in buildings (TS 825) establishes the legal framework for energy performance. Although this standard was officially updated in February 2025 to divide the country into six climatic zones

(Appendix A- Revised Climate Zoning in Türkiye TS 825 – 2025 Update), this study references the TS 825:2013 version which divides the country into four zones.

The specific TOKİ case studies examined in this research were designed and constructed under the framework of the 2013 regulation. Therefore, the climatic zoning map presented in Figure 1, reflects the TS 825:2013 classification to accurately contextualize the passive design criteria and legal obligations in effect during the buildings' production phase.

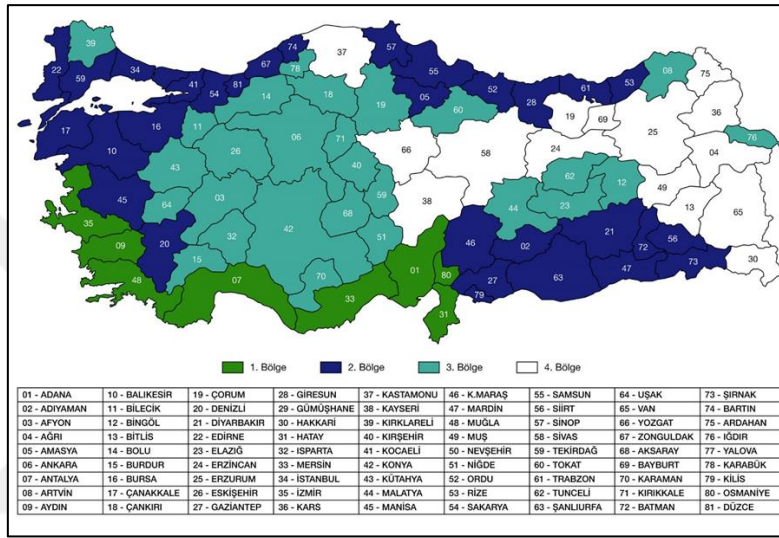


Figure 1. Climate regions according to Turkish building code (Source: TS825, 2013).

2.2. Building Shape and Orientation

Building shape and orientation constitute the primary passive interface between indoor comfort and outdoor climatic conditions. While compactness (low surface-to-volume ratio) is essential for heat conservation in cold climates, extended forms facilitate ventilation in humid zones.

In the context of Türkiye, traditional residential architecture provides a proven archive of such climate-responsive strategies. As classified by Zeren (1987), vernacular forms evolved strictly according to local environmental data; utilizing compact courtyards in hot-dry regions to minimize solar exposure, while adopting linear plans in humid zones for cross-ventilation. Eldem (1968) further typologized elements like the 'Hayat' (semi-open terrace) and 'Sofa' (hall), identifying them not merely as spatial

components but as active thermal buffer zones that function as solar collectors in winter and shaded cooling areas in summer.

However, contemporary housing practices in Türkiye often compromise these principles due to rigid 'parcel-based' zoning regulations. These laws prioritize alignment with street grids over optimal solar azimuth, while strict setbacks limit the flexibility to rotate buildings. As noted by Zeren (1987), this regulatory framework compels the placement of standardized blocks according to administrative boundaries rather than the climatic requirements for ideal solar access (Figure 2).

Climate Zone	Building Form	Building Orientation (Optimum Direction)
HOT-HUMID (Pilot city: Antalya)	Long rectangular form, facing the wind with an open surface 	
HOT-DRY (Pilot city: Diyarbakır)	Courtyard plan, square form, open surface facing the courtyard 	
TEMPERATE-DRY (Pilot city: Ankara)	Compact, nearly square form, closed to the wind during heating periods 	
TEMPERATE-HUMID (Pilot city: İstanbul)	Free plan, large surface area facing the wind, rectangular or other forms 	
COLD (Pilot city: Erzurum)	Compact, square or similar form, minimizing external surfaces, reducing exposure to the wind 	

Figure 2. Building Shape and Orientations by different climatic zones in Türkiye.
(Source: Zeren, 1987)

2.3. Thermal Mass

Thermal mass functions as a passive regulator of indoor temperature by creating a "time lag" between peak outdoor conditions and internal transmission. Historically, Anatolian vernacular architecture relied heavily on high-inertia materials, such as massive stone and adobe (kerpiç) walls exceeding 50 cm, to flatten daily temperature curves in continental climates.

In contrast, contemporary mass housing in Türkiye, particularly TOKİ projects, utilizes reinforced concrete tunnel formwork systems with lightweight infill elements like pumice (bims) blocks. While bims is favored for its insulation properties and

lightness, the resulting wall assemblies possess significantly lower thermal storage capacity compared to traditional masonry. This reduction in thermal inertia results in a "low time-lag" envelope, rendering modern units more susceptible to rapid indoor temperature fluctuations and increasing the demand on mechanical conditioning systems. The MMO advocates for integrating this physical behavior into the building envelope design to reduce energy consumption, a strategy that is often compromised in modern thin-walled construction practices (Figure 3).

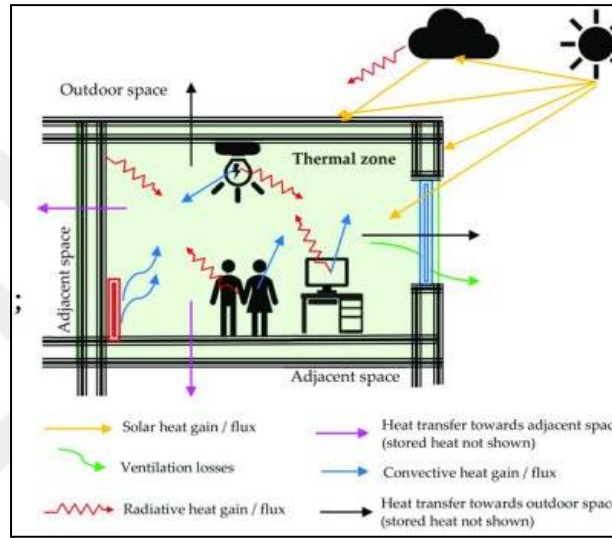


Figure 3. Thermal mass properties in TS 825 (Source: Makina Mühendisleri Odası, 2025).

2.4. Thermal Insulation

Thermal insulation serves as the primary barrier against conductive heat flow. While insulation materials are broadly categorized into "bulk" (resistive) and "reflective" types (Cole, 2011), the Turkish construction sector has overwhelmingly adopted bulk insulation methods following the mandatory enforcement of TS 825 in 2000. This regulatory shift necessitated the widespread use of External Thermal Insulation Composite Systems (ETICS), locally known as "Mantolama". The preference for external application is technically grounded in its ability to wrap the reinforced concrete skeleton continuously, thereby mitigating thermal bridges—a critical requirement for Türkiye's earthquake-resistant frame structures.

According to İZODER (2023), the market is dominated by three primary materials, each selected based on specific building requirements:

- *Expanded Polystyrene (EPS)*: Utilized for its cost-effectiveness in standard low-rise applications.
- *Extruded Polystyrene (XPS)*: Preferred for basements and roofs due to its high compressive strength and moisture resistance.
- *Mineral Wool (Taşyünü)*: Distinguished by its fire resistance. Following recent updates to the Regulation on Protection of Buildings from Fire, the use of non-combustible A-class materials like stone wool has become mandatory for high-rise buildings (typically >21.50 meters).

Consequently, this material has become the standard specification for the majority of recent high-rise TOKİ developments, superseding petroleum-based plastics in vertical applications.

2.5. Window Design and Glazing

In passive solar design, the selection of glazing and Window-to-Wall Ratio (WWR) must be tuned to the specific climate; promoting solar gain in heating-dominated zones while restricting it in cooling-dominated ones (Fahad, 2022). Historically, Turkish residential architecture managed this delicate balance through kinetic elements like the 'Kepen' (wooden shutters), which provided a flexible layer for manual solar control—a capability largely lost in modern "bare window" designs.

In the contemporary construction market, glazing specifications have become heavily standardized around the "4+16+4 mm Clear Double Glazing Unit" (defined by market leaders like Şişecam). As illustrated in Figure 4 (Makina Mühendisleri Odası, 2025), while this configuration provides a baseline U-value acceptable by older standards, it represents a "one-size-fits-all" approach lacking selective coating technology. As shown, solar radiation striking the glass is split into three components: transmission (direct heat gain), reflection (rejected heat), and absorption (heat stored in the glass).

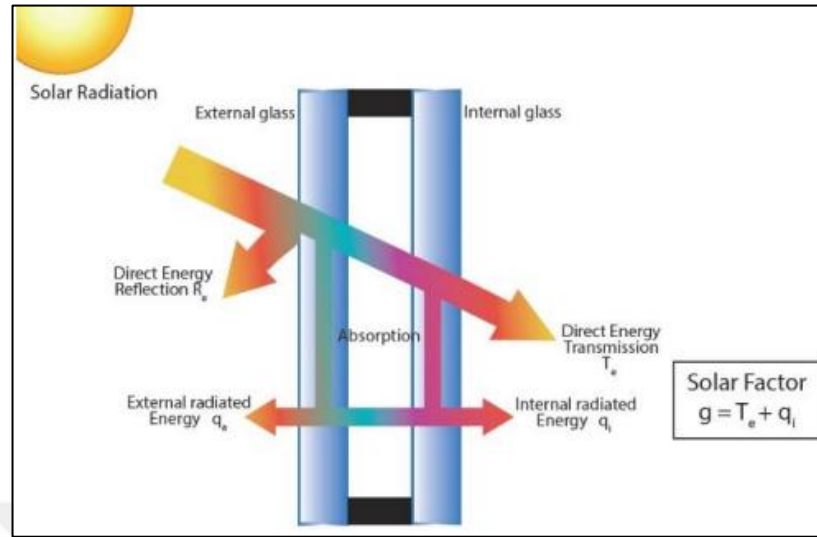


Figure 4. Energy properties of glass in TS 825 (Source: Makina Mühendisleri Odası, 2025).

Consequently, the same clear glass unit is frequently installed in both cold climates (where capturing solar heat is vital) and hot climates (where blocking it is critical). Although advanced coated glasses exist—such as Low-E (Isıcam S) or Solar Control Low-E (Isıcam K)—these are often treated as cost-prohibitive "premium options" in mass housing. Instead, to comply with the mandatory energy limits of TS 825 without investing in high-performance joinery, projects like TOKİ often default to conservative window ratios (typically 15–20%). While this strategy ensures compliance with heating calculations, it inadvertently reduces beneficial solar gain and restricts natural daylight access.

2.6. Shading Elements

Effective solar control relies heavily on the strategic integration of shading devices according to building orientation. As noted by Akalp (2018) and Donn et al. (2010), south-facing façades benefit from horizontal overhangs that block high-angle summer sun while admitting winter light. Conversely, east and west orientations require vertical elements to manage low-angle solar exposure, while hybrid solutions are often necessary for intermediate directions (Cellai et al., 2014; Dutta et al., 2017; Liping and

Hien, 2006). Crucially, Cole (2011) emphasizes that external shading is significantly more efficient than internal methods, as it intercepts radiation before it penetrates the building envelope.

Despite these established principles, modern mass housing in Türkiye has largely abandoned traditional climate-responsive elements. The deep roof overhangs ("Saçak"), which historically functioned as the protective devices described by Cole (2011), have disappeared in current TOKİ typologies due to cost optimization and the prevalence of flat roofs. Similarly, the external shutter ("Panjur") culture has been replaced by bare windows. Consequently, residents are forced to resort to internal heavy curtains—a thermally inefficient solution that traps heat indoors.

A significant deviation in this context is the "Glass Balcony" (Cam Balkon) phenomenon. While balconies are architecturally designed as semi-open shading buffers, a widespread user behavior involves enclosing them with folding glass systems. This intervention eliminates natural airflow and creates an unintended "greenhouse effect," significantly increasing cooling loads in direct contradiction to passive design principles.

CHAPTER 3: MASS HOUSING IN TÜRKİYE

3.1. Mass Housing

Housing is the fundamental spatial unit that meets the physiological need for shelter; however, beyond this physical function, it serves as a reflection of socio-economic status and personal identity (Kellekçi, 2005). It is viewed not only as a living space but also as an economic investment tool and a commodity within the urban market. In this context, "Mass Housing" is defined as a collection of residential units developed in a predetermined settlement area with the support of state-provided loans and subsidies (TDK, 1998). As emphasized by Keleş (1966), these projects differ from individual buildings by being organized as large-scale complexes that include essential social infrastructure such as healthcare, education, and recreational facilities.

The primary objective of mass housing practices is to provide rapid and cost-effective solutions to housing shortages arising from rapid urbanization. According to Keleş (1983), this production model benefits from strategic advantages such as affordable land acquisition, standardized building materials, and industrialized construction techniques that significantly reduce unit costs. By enabling the construction of large numbers of units in short periods, mass housing not only addresses immediate demographic demands but also actively transforms the spatial structure of cities, creating new urban identities through large-scale development zones.

3.2. Development of Mass Housing Production in Türkiye

Following World War II, rapid industrialization and technological advancements in agriculture triggered a massive rural-to-urban migration. Between 1950 and 1960, the urbanization rate exceeded 80%, creating an urgent housing deficit that resulted in the proliferation of unplanned squatter settlements (*gecekondu*) on city outskirts. During this period, state attempts to curb this trend were largely unsuccessful, leading to a dual city structure: planned zones versus spontaneously developed informal areas. As noted by Tutkun (2018), various production models emerged to address these needs, such as cooperatives and the contractor-built "build-and-sell" (*yapsatçı*) system;

however, these methods often failed to provide adequate infrastructure or environmental quality for low-income groups.

A pivotal turning point in the sector occurred on March 17, 1984, with the enactment of the Mass Housing Law No. 2985. This legislation established the Mass Housing and Public Partnership Administration directly under the Prime Ministry, creating a centralized public legal entity to manage housing production. As highlighted by TOBB (1988), this legal framework revitalized the sector by institutionalizing housing loans and funding mechanisms.

By the 2000s, the construction landscape shifted towards high-rise developments, catering to both lower and upper-income groups in city centers (Pilgir, 2015). While private sector actors focused on luxury residences, the Housing Development Administration of Türkiye (TOKİ) underwent significant structural changes, emerging as the dominant actor in the sector. Since the 1990s, TOKİ has centralized the role of the state in housing production, evolving from a funding body into the nation's primary developer of large-scale settlements.

3.3. TOKİ

3.3.1. Historical Development and Institutional Role

According to Tutkun (2018), although TOKİ was originally founded in 1984 to serve merely as a credit mechanism for housing cooperatives, its function underwent a radical transformation following the 2003 Emergency Action Plan. Equipped with new legal mandates—such as the authority to expropriate land and determine zoning regulations independently—the administration evolved from a passive financial supporter into the dominant actor in state-led housing production.

In recent years, the administration has articulated a shift in design philosophy towards "Horizontal Architecture" and "Local Architecture." As noted by Sezen (2023), this concept prioritizes integrating vernacular elements—such as traditional eaves and stone cladding—to reflect regional identity. While this top-down model serves symbolic and ideological functions within the state's development agenda, it aims to replace the earlier high-rise typologies with community-oriented settlements.

The scale of this operation is unprecedented. As of December 2024, TOKİ has completed 1,495,526 housing units, surpassing its cumulative target of 1.2 million. Current strategic objectives, such as the "250,000 Social Housing Project," emphasize sustainability, zero-waste principles, and renewable energy integration for future developments (Milliyet, 2024; Karar, 2024; TOKİ, 2024).

In order to contextualize the scale and territorial reach of TOKİ's current operations, a spatial visualization has been developed based on official data retrieved from the Housing Development Administration's website. The map illustrates the provincial distribution of existing TOKİ housing projects as of July 2025. İstanbul emerges as the province with the highest concentration of projects, followed by Ankara and Hatay.

The relative size of each marker corresponds to the number of projects in that province, thereby enabling a comparative geographic analysis of project density across the national territory. (Figure 5) For a complete list of the number of projects in each province, refer to Appendix B - Distribution of TOKİ Projects by Province, which includes the full dataset used for the spatial analysis.



Figure 5. Geographical distribution of TOKİ housing projects in Türkiye (Based on data from TOKİ, "Projects by Province").

In conclusion, TOKİ remains a pivotal actor in the transformation of Türkiye's housing landscape. While the administration officially aligns its contemporary mission with ideals of spatial quality, cultural representation, and environmental sustainability,

empirical observations indicate disconnect in practice. Therefore, research underscores that fulfilling these declared objectives requires a shift beyond standardized production; to ensure the long-term social and cultural viability of state-led housing, adopting participatory and user-responsive design strategies is essential.

3.3.2. TOKİ Housing Typologies and Apartment Layouts

In TOKİ's social housing schemes, particularly within the recent "İlk Evim" (My First Home) initiative, the most prevalent typologies are standardized 2+1 (70–85 m²) and 3+1 (100–120 m²) units (TOKİ, 2023). TOKİ's housing projects commonly follow uniform plan and façade configurations, which are largely replicated across various climatic and geographic regions in Türkiye. Visual evidence from TOKİ's official project gallery indicates a high degree of repetition in architectural form, orientation, and block arrangement, regardless of local context (TOKİ, 2025). This reflects an institutional preference for production efficiency and construction speed over climatic adaptation or architectural variation.

Spatially, these apartment layouts adhere to a rigid, standardized rectilinear scheme, where functional spaces are aligned along a central axis to optimize circulation. As illustrated in Figure 6, representative examples from Afyon, Balıkesir, and Nevşehir demonstrate this approach. Crucially, building performance is heavily influenced by site-specific parameters such as orientation and the shadowing effects of surrounding structures.

However, despite being located in distinct climatic zones, these projects exhibit an identical typology in both plan organization and site implementation. The only noticeable variation—the presence of a single versus double elevator core—is strictly dictated by zoning regulations rather than climatic adaptation. In blocks with fewer than 20 independent units, the secondary elevator shaft is simply converted into a technical room without altering the overall layout (Figure 6). Consequently, the visual evidence suggests that the blocks are positioned with little regard for optimal solar orientation or local texture, effectively treating the diverse environmental constraints of these three cities as if they were identical.



Figure 6. Floor Plan of Afyon (a), Balıkesir (b) and Nevşehir (c) TOKİ Houses

Overall, this typological standardization, while administratively and economically advantageous, poses challenges for energy-efficient design. The absence of adaptive strategies tailored to different climatic zones underscores the relevance of this study's comparative case analysis.

3.3.3. Common Construction Materials and Building Envelope Features

TOKİ developments predominantly employ tunnel formwork systems with reinforced concrete frames and infill walls to ensure rapid construction (TOKİ, 2022). While roofing typologies vary between flat slabs and inclined forms depending on local precipitation levels, the structural material palette remains highly standardized.

Regarding the building envelope, recent projects demonstrate a notable shift toward mineral wool insulation in wall and roof assemblies. This preference is driven by the material's thermal efficiency and compliance with fire safety standards (TOKİ, 2023; Izocam, 2020). This aligns with broader market trends in Türkiye, where high-performance envelope solutions are increasingly replacing traditional methods (YapıFuarı, 2018).

Fenestration typically consists of standard PVC or aluminum frames with double glazing, designed to meet baseline TS 825 U-value requirements (TOKİ, 2021). However, the impact of these standardized choices is significant. As highlighted by Süer and İlerisoy (2022), wall material selection (e.g., brick vs. pumice) can result in up to a 25% variation in energy consumption. This evidence underscores the necessity of evaluating TOKİ's uniform material specifications against specific regional climatic demands in the following case studies.

3.3.4. Design Approach in Different Climatic Zones

TOKİ's mass housing framework displays a notable degree of design uniformity across Türkiye's diverse climatic regions. According to the institution's project repository, architectural layouts, façade compositions, and building configurations are consistently replicated across locations—ranging from Mediterranean coastal zones to cold, inland regions—with minimal adaptation to local climatic conditions (TOKİ, 2025). This generic application of standardized models supports rapid construction, streamlined procurement, and minimized administrative complexity.

From the perspective of thermal regulation and energy performance, this standardized approach imposes significant limitations. Although recent research highlights the necessity of distinct climatic zoning for effective insulation strategies (Yıldız and Argunhan, 2021), TOKİ's uniform architectural typology often fails to reflect this

zonal differentiation. Consequently, identical prototype designs are implemented in both heating-dominated and cooling-dominated regions, lacking the necessary site-specific adjustments—such as optimized orientation, appropriate glazing ratios, or shading elements—that are essential for enhancing passive performance.

While this structural repetition optimizes production efficiency, it frequently compromises thermal comfort, reflecting a broader policy issue where typological standardization overrides contextual responsiveness. Against this backdrop, the study utilizes these observations not merely to conduct a comparative performance assessment, but to ground a methodological proposal. The primary objective is to develop and validate a comprehensive evaluation workflow. Accordingly, the application of this framework across two climatically contrasting pilot regions serves as a proof-of-concept; it aims to demonstrate how the proposed methodology effectively integrates simulation tools with resident feedback to reveal performance gaps, thereby offering a replicable model for future climate-sensitive design strategies.

CHAPTER 4: CASE STUDIES: COMPARATIVE ANALYSIS OF TOKİ HOUSING IN TWO CLIMATIC ZONES OF TÜRKİYE

4.1. Climatic Assessment of Aydın & Yozgat

Aydın and Yozgat were selected to represent contrasting climatic extremes within Türkiye's national classification system. Aydın (1st Climatic Zone) is characterized by a hot-humid climate where the primary design challenge is controlling overheating and managing solar gain. In contrast, Yozgat (4th Climatic Zone) represents the continental interior, where severe winters dictate a necessity for effective thermal insulation and compact forms to minimize heat loss.

The climatic assessment presented in this section relies on Typical Meteorological Year (TMY) data, processed through Climate Consultant software. To ensure compatibility with national standards and scientific literature, all temperature values are presented in Celsius (°C). Accordingly, the comparative analysis is structured around four key graphical outputs: Temperature Range Diagram, Radiation Range Diagram, Sun Shading Chart and Psychrometric Chart.

The 'Temperature Range' analysis identifies thermal dominance (heating vs. cooling) by mapping diurnal fluctuations against the comfort zone (Figure 7).

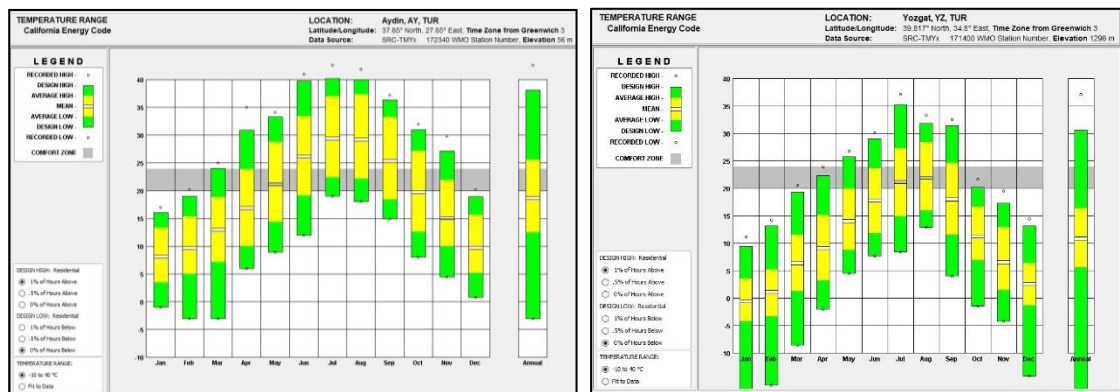


Figure 7. Temperature Range Diagram of Aydın & Yozgat (Data Source: Climate Consultant).

The comparative assessment of Temperature Range diagrams (Figure 7) reveals a fundamental dichotomy. Aydın is characterized by chronic overheating (reaching 42°C) and mild winters, necessitating a building envelope optimized for heat rejection. Conversely, Yozgat faces transient summer heat but severe cold stress (plunging below -15°C), requiring maximum heat retention. The most critical operational distinction, however, lies in the diurnal temperature swing. Yozgat's wide daily fluctuations indicate that passive strategies like night ventilation and thermal mass would be highly effective for cooling. In contrast, Aydın's persistently high ambient temperatures limit the potential of night flushing, compelling a design strategy focused primarily on high-performance solar shading and insulation rather than natural ventilation.

Solar radiation drives thermal dynamics, serving as a vital heat source in winter and an overheating liability in summer. The 'Radiation Range' analysis quantifies Global Horizontal and Direct Normal Radiation (Wh/m²) to optimize this balance. Crucially, this metric informs the envelope strategy by identifying specific periods for maximizing passive solar gain versus implementing mandatory shading to maintain indoor comfort.

The comparative assessment of radiation data (Figure 8) reveals that while both provinces possess high solar energy potential, the architectural management of this energy must be diametrically opposed due to the underlying temperature profiles.

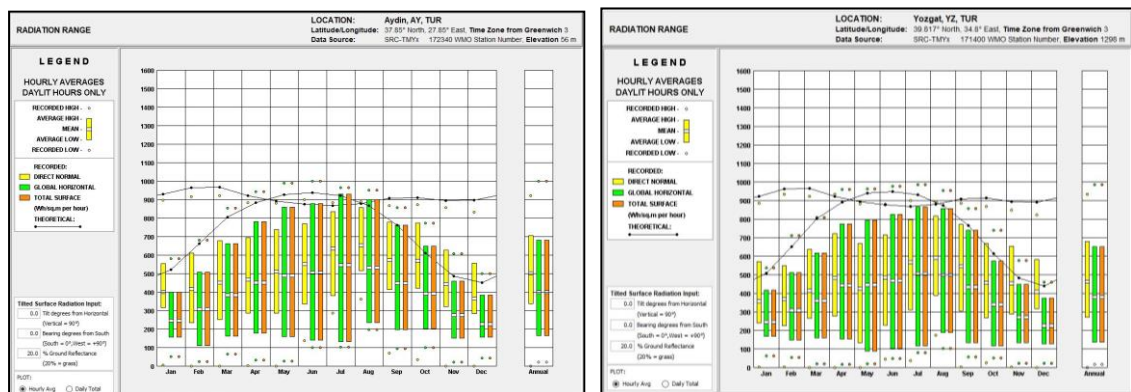


Figure 8. Radiation Range Diagram of Aydın & Yozgat (Source: Climate Consultant)

The comparative analysis of solar radiation (Figure 8) dictates diametrically opposed architectural strategies. In Aydın, peak radiation intensities (900–1000 Wh/m²)

coincide with extreme ambient heat, making 'solar exclusion' the absolute priority to mitigate severe cooling loads. Conversely, Yozgat reveals a critical opportunity: despite freezing ambient temperatures, winter radiation remains significant (300–500 Wh/m²). This validates the potential for 'passive solar heating' to drastically lower heating demand. Therefore, the essential design divergence is clear: while Aydın requires rigid protection against solar ingress, Yozgat demands a dynamic envelope capable of harvesting solar gain in winter while providing adjustable shading during the brief summer peak.

The Sun Shading Chart functions as a temporal map for solar control by overlaying hourly thermal data onto the sun's path. It visually differentiates between overheating periods (red points) requiring mandatory shading and heating-dominated hours (blue points) where passive solar gain is beneficial. This analysis is critical for defining the precise operational schedule for shading devices.

The Sun Shading Chart (Figure 9) dictates two conflicting design imperatives based on operational hours. Aydın requires shading for 651 hours annually (May–October), necessitating fixed architectural elements to permanently block high-angle radiation. In sharp contrast, Yozgat is dominated by a heating requirement of 2187 hours, with shading needed for only 111 hours. Crucially, applying Aydın's fixed shading strategy to Yozgat would be detrimental, as it would obstruct essential winter gain. Therefore, unlike the static needs of Aydın, Yozgat demands movable or dynamic shading systems that mitigate brief summer overheating without compromising the dominant need for passive solar heating.

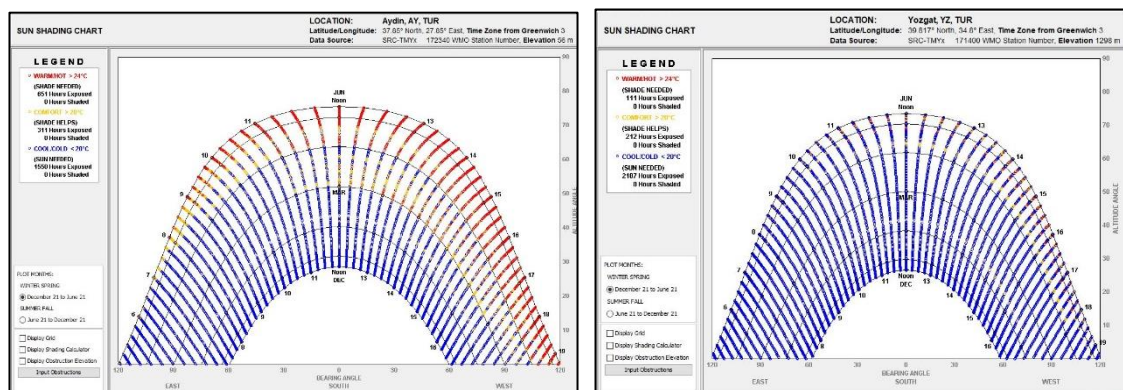


Figure 9. Sun Shading Chart of Aydın & Yozgat (Source: Climate Consultant)

The Psychrometric Chart serves as the primary diagnostic tool for defining passive design strategies. By mapping hourly climatic data against the comfort zone, it not only quantifies natural comfort periods but also prescribes specific architectural interventions—such as thermal mass or natural ventilation—required to extend occupant comfort without mechanical reliance. The comparative review of the Psychrometric Charts (Figure 10) serves as the definitive proof that a standardized building envelope cannot function effectively in both locations.

The Psychrometric analysis reveals a stark contrast in required interventions. In Aydın, where base comfort is limited to 12.9%, the priority is heat rejection. The chart identifies Sun Shading of Windows as the single most critical strategy, extending comfort by 1855 hours (21.2%), followed by ventilation strategies like Night Flushing (13.3%). Conversely, Yozgat suffers from a severe heating deficit (base comfort 7.4%), with active heating required for 38.4% of the year. However, the chart highlights a major passive opportunity: Passive Solar Direct Gain can resolve 24.9% of the discomfort. Thus, the design imperative is clear: Aydın demands a 'defensive' envelope focused on shading and airflow, while Yozgat requires an 'absorptive' envelope designed to harvest solar energy.

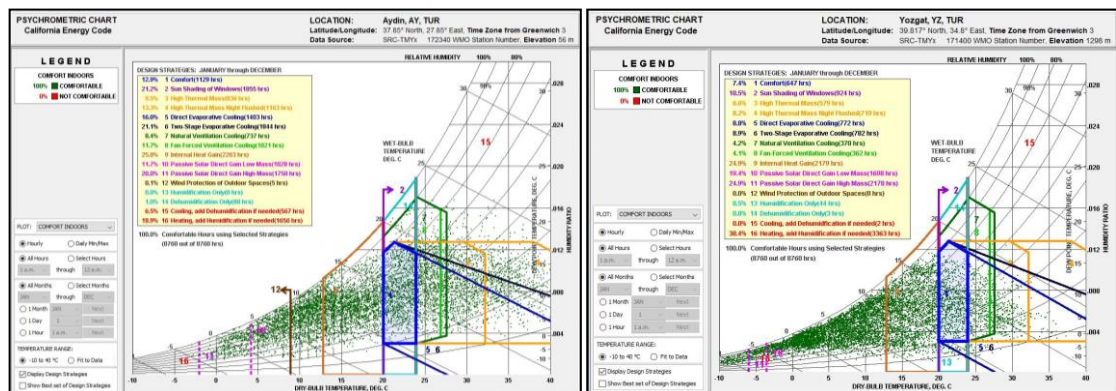


Figure 10. Psychrometric Chart of Aydın & Yozgat (Source: Climate Consultant)

The comprehensive climatic analysis confirms that Aydın and Yozgat represent antipodal thermal environments, necessitating diametrically opposed architectural responses. Consequently, the application of a standardized housing typology across these distinct zones is fundamentally flawed. The data proves that energy efficiency in

mass housing cannot be achieved through repetitive templates, but only through site-specific algorithmic adaptation.

4.2. Building Typology and Construction Characteristics of Aydın & Yozgat

The housing developments in Aydın and Yozgat share a similar mid-rise building typology, generally composed of four to six-story apartment blocks arranged in compact layouts typical of Turkey's mass-housing schemes. In both regions, reinforced concrete frame systems are used as the primary structural solution, ensuring seismic safety, durability, and cost efficiency. However, while Aydın's construction practices respond to the hot and dry Mediterranean climate, Yozgat's designs are adapted to the cold continental conditions of Thermal Zone 4 as defined by the TS 825 standard.

A key distinction lies in the thermal envelope design. In Aydın, external walls typically feature limited insulation combined with light-colored plaster finishes to reflect solar radiation and reduce overheating. In contrast, Yozgat's buildings integrate External Thermal Insulation Composite Systems (ETICS) with EPS, XPS, or mineral wool layers, minimizing heat loss during prolonged winters. This difference reflects the opposing climatic demands—cooling-dominated in Aydın and heating-dominated in Yozgat.

Regarding glazing, both cities use double-glazed PVC windows. In terms of façade characteristics, the observed typology contradicts expected climatic logic. Contrary to the theoretical requirement for minimized apertures in cold regions, the Yozgat case study features significant glazing areas—comparable to or even exceeding those in Aydın—rather than smaller, heat-retentive openings. Furthermore, neither project incorporates specialized shading devices (such as louvers or brise-soleil). Solar control is limited solely to the incidental shadowing provided by standard balconies, which are present in both designs regardless of orientation or thermal necessity. This lack of differentiation confirms that the façade design prioritizes modular repetition and standardization over the specific thermal requirements of the site.

Roof typologies also vary according to climatic requirements. Aydın typically features moderately pitched, tiled roofs, which facilitate rainwater drainage and reduce upper-

floor overheating. In Yozgat, low- to medium-pitched roofs are used instead, designed to withstand snow loads and prevent accumulation during winter months.

A significant disconnect is observed in the mechanical systems. Despite the antipodal climatic requirements—where Aydın is cooling-dominated and Yozgat is heating-dominated—both housing estates employ an identical central natural gas heating system. While this infrastructure aligns well with Yozgat’s severe winter conditions, it creates a functional gap in Aydın. In the hot-climate case, the design prioritizes a centralized heating solution that is utilized for only a few months, while completely neglecting the dominant cooling load. Consequently, the essential requirement for active cooling is left unaddressed by the building design, forcing residents to rely on ad-hoc, retrofitted individual air-conditioning units.

In summary, both regions utilize similar structural and organizational principles, yet their envelope design, orientation, and mechanical systems diverge according to climatic necessity. Aydın’s housing prioritizes solar control and passive cooling, while Yozgat’s design emphasizes thermal insulation and passive heating. This comparison underscores the importance of regional climatic adaptation in standardized housing, illustrating how identical structural systems can yield different environmental performances when exposed to contrasting climatic realities.

4.3. Evaluation of the Selected TOKI Housings in Aydın & Yozgat

4.3.1. Location and Site Context

The two selected TOKİ housing projects are located in different climatic and geographical regions of Turkey, reflecting the country’s environmental diversity and the necessity for regionally responsive design approaches. The first project, situated in the Nazilli district of Aydın, lies within Turkey’s 1st Climatic Zone, characterized by hot and dry summers and mild, rainy winters under the influence of the Mediterranean climate. The second project, located in Dogankent within the Sorgun district of Yozgat, belongs to the 4th Climatic Zone and represents the cold continental climatic conditions of Central Anatolia.

The Aydın–Nazilli project (constructed 2023–2024, seven blocks) and the Yozgat–Doğankent project (completed 2022, six blocks) serve as concrete evidence of

typological repetition. Despite occupying antipodal climatic zones, both developments strictly enforce an identical 'perimeter block' strategy. In this layout, building masses are aligned primarily with the street axis and property lines—strictly adhering to zoning setbacks—to create a protected inner courtyard for social amenities.

However, this rigid prioritization of the 'road axis' over the 'solar axis' represents a critical design oversight. By treating the site layout purely as a function of parcel geometry rather than environmental performance, the orientation of the blocks remains static across both projects. Consequently, the buildings in the hot-humid climate of Aydın and the cold-continental climate of Yozgat are subjected to the same solar exposures and wind patterns. This lack of differentiation confirms that the site planning was driven by administrative compliance rather than climate-responsive adaptation, effectively ignoring the unique thermal requirements of each location. For a comprehensive visual overview, including general layout plans, aerial views, and photographic documentation of façades and open spaces, refer to Appendix C- Visual Documentation of Selected TOKİ Projects.

4.3.2. Orientation and Plan Typology

Both housing projects in Aydın and Yozgat display remarkably similar spatial and plan typologies, reflecting the standardized design logic of TOKİ's mass housing approach. Despite being located in contrasting climatic zones, the building orientation and internal organization remain almost identical, suggesting limited adaptation to environmental context.

In Aydın, the complex comprises seven blocks—five blocks accommodating 2+1 units (Figure 11) and two blocks with 3+1 units (Figure 12). Each floor includes four units, producing 20 dwellings per block. In total, the site includes 99 units within the 2+1 blocks (approximately 100 m² each) (Figure 11), and 40 units within the 3+1 blocks (approximately 120 m² each) (Figure 12). The buildings are designed as Basement + Ground Floor + 4 Floors.

In Yozgat, the residential complex consists of six blocks, each configured as Basement + Ground Floor + 3 Floors. Each floor accommodates four 2+1-type apartments,

resulting in 20 units per block and a total of 96 units, each with an average net area of 100 m² (Figure 13).

The floor plan layouts of both projects are symmetrical, organized around a central shared staircase and elevator core. Upon entering each apartment, the living room and kitchen are positioned on the façade-facing side, while the bathroom and WC are placed adjacent to the party wall between two mirrored units. Next to the bathroom lies the master bedroom, and a second bedroom is located at the corner, benefiting from dual façades. In Aydın's 3+1 units, this typology is extended by inserting an additional corner room between the two existing bedrooms.

In both projects, the living rooms of two mirrored apartments face north, while those of the opposite mirrored pair face south, creating an internally symmetrical but climatically neutral plan. The only notable difference between the two designs lies in the positioning of the shared staircase and elevator core—in Aydın, they are oriented toward one façade, while in Yozgat, they are symmetrically centered relative to the building mass. All spatial and typological descriptions in this study are based on original project documents, including architectural plans and elevations. The orientation analysis follows the north direction as marked in the official drawings.



Figure 11. Aydın TOKI Housing Complex, 2+1 Floor Plan (Source: Aydın, TOKI)

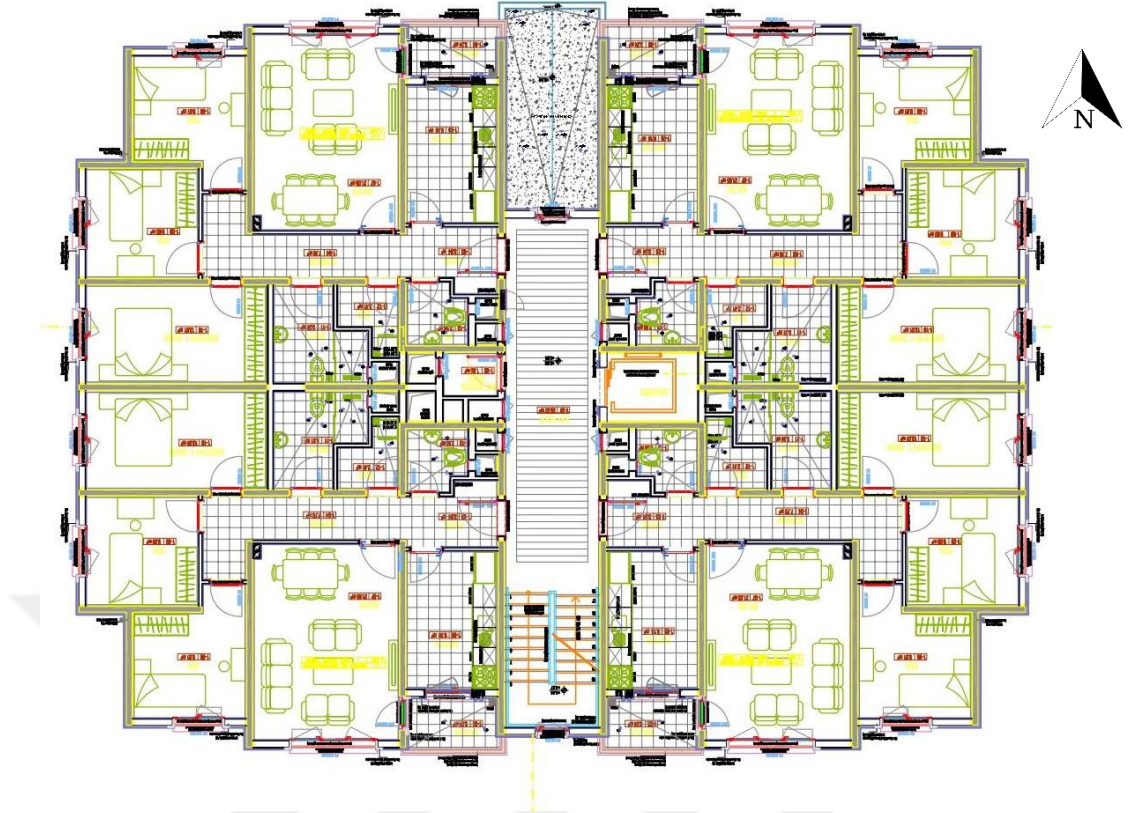


Figure 12. Aydın TOKI Housing Complex, 3+1 Floor Plan (Source: Aydın, TOKI)

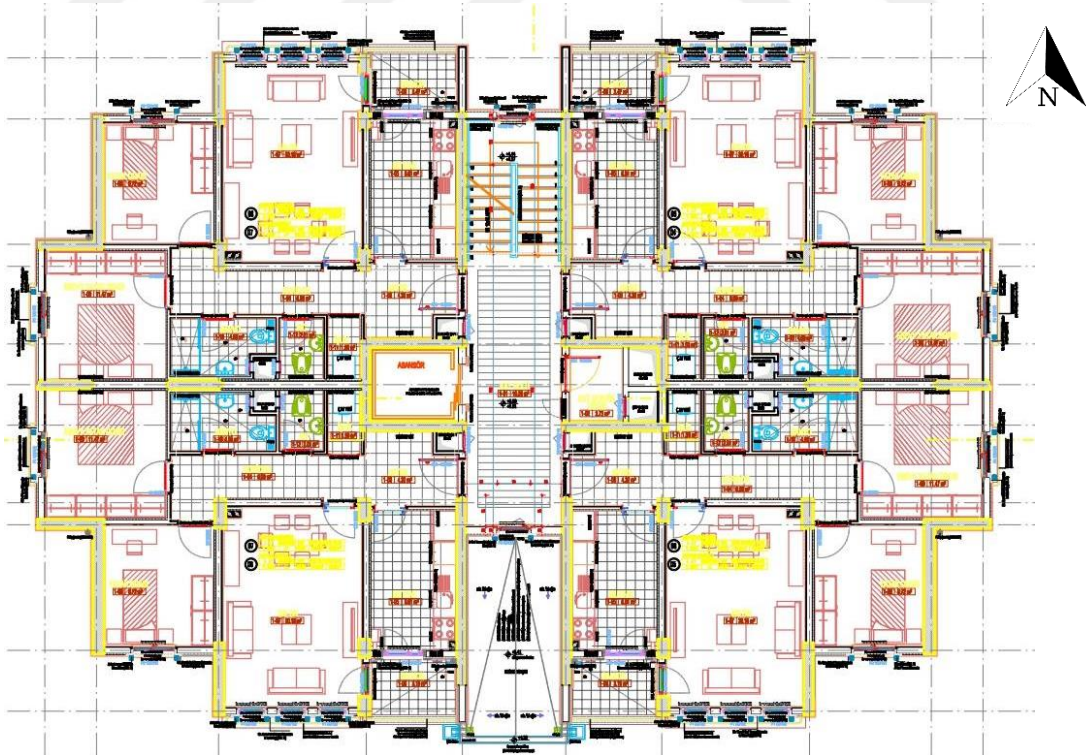


Figure 13. Yozgat TOKI Housing Complex, 2+1 Floor Plan (Source: Yozgat, TOKI)

Overall, the comparative analysis reveals that while Aydın and Yozgat differ climatically, their orientation and plan typology remain virtually the same. This uniformity indicates that climatic factors had minimal influence on spatial organization. The replication of identical floor plans in both a cooling-dominated (Aydın) and heating-dominated (Yozgat) context highlights the limited environmental adaptability of standardized mass-housing models.

4.3.3. Material and Building Envelope Properties

The material characteristics and envelope specifications of the selected TOKİ housing units were analyzed based on the "System Details" provided in the architectural implementation projects. While the structural skeleton exhibits the typical standardization of mass housing, specific variations in roofing, insulation thickness, and fenestration ratios reflect distinct approaches to climatic adaptation.

Both the Aydın and Yozgat housing projects utilize a standardized tunnel formwork system, characterized by shear-wall dominant reinforced concrete structures supported by mat foundations. This system is prioritized primarily for seismic safety and rapid construction capabilities rather than thermal performance. The technical drawings regarding these structural features are included in Appendix D – Construction Details of Building Envelope Elements.

The roof systems in both cases feature hipped wooden structures with a 33% slope to ensure effective precipitation drainage. However, material selection differs based on regional requirements:

- Aydın (Hot-Dry): Utilizes clay roofing tiles (Appendix D, Figures 31 & 32), which are thermally advantageous for reflecting solar radiation and minimizing heat absorption in summer.
- Yozgat (Cold-Continental): Employs metal roofing tiles, selected for their durability against heavy snow loads and freeze-thaw cycles, typical of the region's harsh winters. In both instances, a layer of stone wool insulation and waterproofing membranes is applied beneath the roof covering to improve thermal resistance (Appendix D, Figure 33).

The opaque building envelope in both projects consists of 20 cm vertically perforated brick walls finished with external plaster and acrylic-based paint (Appendix D, Figures 34 & 35). The differentiation lies in the thermal insulation thickness applied within the External Thermal Insulation Composite System (ETICS):

- Aydın: Features an EPS insulation layer of approximately 3–4 cm (Appendix D, Figure 38).
- Yozgat: Employs a similar wall composition but utilizes thicker EPS insulation (typically 5–6 cm) to combat the significantly higher heating loads (Appendix D, Figure 39).

A critical "performance gap" is observed in the fenestration systems. Despite the contrasting climatic needs, both projects utilize the standard 4+16+4 mm clear double-glazing units (Appendix D, Figures 36 & 37).

This uniform application is thermally suboptimal. In Aydın's cooling-dominated context, Solar Control Low-E units would be more appropriate to block solar heat gain. Conversely, in Yozgat's heating-dominated climate, Low-E (coated on the inner surface) or triple-glazed units with argon fill would significantly reduce conductive heat loss.

Furthermore, frame materials differ; Aydın uses anthracite-colored PVC profiles (better thermal resistance) (Appendix D, Figure 36), whereas Yozgat employs aluminum frames (Appendix D, Figure 37), which, despite their structural durability, introduce greater thermal bridging risks in a cold climate.

Window-to-Wall Ratio (WWR) Analysis the Window-to-Wall Ratio (WWR) is a key parameter determining the building's interaction with solar radiation and daylight. It is calculated using the following formula:

$$\text{WWR} = (\text{Total Window Area} / \text{Total Façade Area}) \times 100$$

Where the total window area is the sum of all glazed openings, and the total façade area includes all opaque and transparent surfaces of the respective elevation. The analysis of façade dimensions reveals a divergence in design strategy between the two cities:

- Aydın: Exhibits an overall average WWR of 20% (27% on North-South / 8.6% on East-West).
- Yozgat: Displays a higher overall WWR of 24% (23.3% on North-South / 25.7% on East-West).

These façade dimensions and window arrangements are illustrated in Figure 14 and Figure 15.



Figure 14. North-South Elevation Drawing, East-West Elevation Drawing of Aydın TOKI Building



Figure 15. North-South Elevation Drawing, East-West Elevation Drawing of Yozgat TOKI Building

The North and South elevations exhibit identical fenestration and balcony placement, mirroring the equally symmetrical East and West façades. Additionally, the East-West axis features a significantly reduced window density compared to the North-South sides.

While Chanda and Biswas (2025) discuss the varying approaches to fenestration in vernacular architecture, the data from these case studies aligns with modern passive solar design principles regarding solar gain. In heating-dominated climates like Yozgat, the primary objective is to maximize the intake of solar radiation during winter months to reduce heating loads.

In this context, the higher Window-to-Wall Ratio observed in Yozgat (24%) can be interpreted as a beneficial strategy, as it increases the potential for passive solar heat gain. Conversely, in cooling-dominated climates like Aydın, the priority shifts to preventing overheating by limiting direct solar exposure. The lower Window-to-Wall Ratio in Aydın (20%) aligns with this objective by minimizing the surface area exposed to intense solar radiation, thereby reducing the cooling load.

The comparative summary of all building materials and envelope properties for both pilot areas is presented in Table 1.

Table 1. Building Materials & Envelope Properties in Aydın/ Yozgat TOKI Buildings

Building Element	Aydın (1st Climatic Zone)	Yozgat (4th Climatic Zone)
Wall Insulation	20 cm vertically perforated brick wall + exterior plaster + ETICS (EPS insulation layer of approximately 3–4 cm)	20 cm brick wall + exterior plaster + ETICS (EPS insulation layer of approximately 5–6 cm)
Floor Insulation	Thermal insulation (30 mm XPS) - Sound insulation ($\approx$ 3–5 mm)	Thermal insulation (60 mm XPS) - Sound insulation ($\approx$ 3–5 mm)
Roof Insulation	Stone Wool Mattress-Membrane (3-4 mm)	Stone Wool Mattress-Membrane (3-4 mm)
Roof Type	Clay Roofing tile Wooden Hipped Roof (33% slope)	Metal Roofing Tile Wooden Hipped Roof (33% slope)
External Finish	Acrylic Based Exterior Paint	Acrylic Based Exterior Paint
Glazing	Double Glazing 4+16+4	Double Glazing 4+16+4

Table 1 (continued). Building Materials & Envelope Properties in Aydın/ Yozgat TOKI Buildings

Building Element	Aydın (1st Climatic Zone)	Yozgat (4th Climatic Zone)
Window Orientation / Ratio	North–South façades WWR $\approx$ 27%; East–West façades WWR $\approx$ 8.6%; area-weighted average $\approx$ 20%	North–south façades WWR $\approx$ 23.3%; east–west façades WWR $\approx$ 25.7%; area-weighted average $\approx$ 24.0%.
Shading Elements	Balcony Projections	Balcony Projections
Heating System	Central Heating Boiler , Natural Gas	Central Heating Boiler , Natural Gas
Foundation Type	Mat Foundation	Mat Foundation
Frame Materials	Anthracite PVC Profiles	Aluminum Profiles

CHAPTER 5: SURVEY

5.1. Survey Design and Methodology

5.1.1. Aim and Rationale

Energy use in buildings is closely connected to operational characteristics, space utilization, and, most importantly, the behavior of occupants. Occupants influence building performance not only through their mere presence and daily activities, but also through control actions intended to improve indoor environmental conditions such as thermal comfort, air quality and lighting (Hoes et al., 2009). This highlights the critical role of user behavior in shaping the actual effectiveness of passive energy design strategies.

As mentioned, the examination of the Yozgat and Aydın housing complexes serves primarily to validate the 'occupant feedback' component of the proposed evaluation workflow. While building simulation models typically rely on standardized usage assumptions, actual performance is heavily influenced by unpredictable adaptive behaviors—such as window operation or shading adjustment—creating a 'performance gap' between theory and reality. To bridge this divide, the proposed methodology mandates the integration of occupant surveys as a fundamental layer of analysis. Consequently, the surveys conducted in these pilot regions are not merely intended to assess local satisfaction levels, but to demonstrate how qualitative user data can be systematically incorporated to calibrate quantitative simulation results and ensure a comprehensive performance assessment.

5.1.2. Target Participants and Demographics

The survey was administered to residents of selected TOKİ housing complexes in both Aydın and Yozgat. Participation was open to all adult occupants over the age of 18, regardless of whether they were homeowners or tenants. By not restricting participation to ownership status, the study ensured that both long-term and short-term residential experiences were represented.

Particular attention was given to individuals who spend extended periods of time at home, such as retirees, homemakers, or individuals engaged in remote work. This sampling strategy was intentional, as such participants are more directly exposed to fluctuations in indoor thermal comfort, daylight access, and the performance of construction materials throughout the day. Their daily routines allowed them to observe and report subtle differences in how seasonal conditions and building characteristics influence comfort levels. In addition, participants were deliberately selected from different floor levels, including ground-floor, mid-level, and top-floor apartments. This diversity was considered essential, as the position of a dwelling within the building significantly affects solar exposure, ventilation, and thermal losses.

In the Aydın TOKİ housing complex, a total of 139 residential units were identified, of which 36 households participated in the survey, representing approximately 26% of the total population. In the Yozgat complex, which consists of 96 units, interviews were conducted with 23 households, corresponding to approximately 24% participation. These participation rates are considered sufficient for the scope and purpose of this research. Given that the study adopts an exploratory and comparative approach focusing on user comfort perceptions and adaptive behaviors rather than large-scale statistical generalization, the achieved sample sizes provide adequate representation for identifying trends and drawing meaningful inferences.

In total, the survey was conducted with 59 participants, including 36 residents in Aydın and 23 residents in Yozgat. This demographic composition provided a diverse mix of age groups, household structures, tenures, and dwelling positions, thereby strengthening the reliability of the findings. The variety of respondents allowed the study to highlight not only common challenges but also variations in adaptive strategies that emerge among different user profiles and apartment configurations within the same housing typologies.

5.1.3. Survey Content

The survey was structured around four main thematic areas that directly reflect the lived experience of passive energy strategies in the selected housing complexes. In total, the questionnaire included twelve structured questions covering thermal comfort, solar access, ventilation practices, and material performance. These questions were

designed in mixed formats, including five-point Likert scale questions, yes/no questions, and a limited number of open-ended questions that allowed participants to elaborate on their experiences. The complete survey form and answers are presented in Appendix E – Survey Questionnaire & Answers.

The first theme focused on thermal comfort, asking residents to evaluate seasonal comfort conditions, including experiences of overheating in summer and under heating in winter. This dimension aimed to capture how well the dwellings supported stable indoor comfort across different climatic conditions.

The second theme addressed solar access and daylight utilization, examining residents' perceptions of the adequacy of sunlight within their apartments, as well as their strategies for controlling or enhancing solar gains. This included questions related to shading practices, the use of curtains or blinds, and satisfaction with natural lighting throughout the year.

The third theme concentrated on ventilation practices, particularly the frequency and timing of window openings, the role of shading devices in managing airflow, and the adequacy of natural ventilation in maintaining indoor air quality. This aspect was considered essential, as ventilation directly interacts with thermal comfort and overall energy demand in naturally conditioned dwellings.

Finally, the fourth theme explored material performance, addressing occupant perceptions of walls, windows, and roofing elements in relation to heat loss, moisture problems, and durability. Participants were also invited to report any additional measures or modifications they had undertaken, such as installing extra insulation, replacing windows, or adopting specific household practices to improve indoor conditions.

Taken together, these thematic areas provided a comprehensive overview of how residents perceive, adapt to, and modify their living environments, thereby offering insights that complement the technical findings of the simulation studies.

5.1.4. Implementation Process

The survey was conducted during on-site visits to the selected TOKİ housing complexes in Aydın and Yozgat. All participants were informed at the outset that the

study was part of an academic thesis, and their voluntary participation was requested. Prior to participation, the purpose of the survey was explained clearly, and verbal consent was obtained.

All surveys were conducted in person, with questionnaires administered face-to-face to participants during on-site visits to each housing complex. Responses were first recorded on paper and subsequently digitized for analysis. No personal information such as names or contact details was collected, in order to preserve participant anonymity. Each interview lasted approximately 15 to 20 minutes, allowing respondents to elaborate on their experiences where necessary.

A total of 59 residents—36 in Aydın and 23 in Yozgat—took part in the survey. Participants were selected from different blocks within the housing complex, rather than from a single building, in order to capture variations arising from building orientation and positioning. Similarly, surveys were conducted on different floor levels—including ground, middle, and top floors—to account for differences in solar exposure, ventilation, and thermal losses associated with vertical position in the building.

5.2. Survey Results

In Aydın, a total of 36 residents participated in the survey, representing a diverse range of household types and demographic backgrounds. Among these participants, 47.2% were between the ages of 30 and 50, indicating that the responses largely reflect the perceptions of working-age adults with substantial household responsibilities. In terms of gender distribution, 55.6% of the respondents were women, which is consistent with the survey design that prioritized individuals who spend extended periods of time at home. This demographic profile ensured that the collected data captured perspectives from those most directly exposed to indoor environmental conditions and building performance on a daily basis.

In Yozgat, a total of 23 residents participated in the survey, representing a broad range of household profiles within the selected TOKİ housing complex. Among the respondents, 60.9% were between the ages of 30 and 50, indicating that the survey predominantly captured the experiences of middle-aged residents who are actively

engaged in daily household routines. In terms of gender distribution, 69.6% of the participants were women, reflecting the study's emphasis on individuals who spend more time at home and are therefore more aware of indoor environmental conditions. This demographic profile ensured that the collected data accurately reflected users' day-to-day experiences of comfort, solar exposure, and material performance within their dwellings.

5.2.1. Thermal Comfort

The comparative analysis of winter comfort exposes a fundamental failure in the standardized envelope's ability to respond to antipodal climates. In the mild Zone 1 (Aydın), the reported 'mediocre' satisfaction (Score: 3/5) is architecturally unjustifiable; it indicates that despite favorable conditions, the building lacks the necessary airtightness to retain internal gains. Conversely, in the harsh Zone 4 (Yozgat), the high dependency on mechanical heating (Score: 4/5) confirms that the envelope fails both as a thermal buffer and a solar collector. This contrast highlights a shared 'performance gap': in Aydın, the design wastes natural warmth through poor insulation, while in Yozgat, it ignores the critical potential of passive solar heating due to static orientation, forcing residents in both scenarios to compensate for design flaws with active energy consumption (Appendix E, Figure 40).

Summer conditions reveal a sharp climatic dichotomy that exposes the critical failure of the standardized façade in hot climates. In Aydın, the high dependency on mechanical cooling (41.7% reporting maximum need) confirms that the unshaded envelope functions as a 'heat trap,' failing to implement the necessary 'defensive' strategy against solar gain. Conversely, Yozgat exhibits a natural resilience where cooling dependency is significantly lower (39.1% reporting low need), a result attributed to the region's substantial diurnal temperature swings (cool nights). This comparison validates that while the identical unshaded design is structurally tolerable in the forgiving continental summer, it becomes a severe liability in the hot-humid zone, forcing Aydın residents to retrofit active cooling solutions into a building infrastructure that ignored the dominant cooling load (Appendix E, Figure 41).

In response to these thermal challenges, the survey results confirm that 'comfort' is actively manufactured by residents through remedial strategies rather than provided

by the architecture. The strikingly high intervention rates in both cities (80.6% in Aydın, 95.7% in Yozgat) reveal a critical disconnect between design intent and operational reality. In the mild climate of Aydın, the widespread use of improvised measures like window sealing tape serves as an indictment of construction quality, exposing significant air-tightness failures in the joinery. Meanwhile, in Yozgat, the extensive use of wall-to-wall carpeting and heavy drapes introduces a fundamental thermodynamic shift: these layers effectively 'decouple' the interior air from the concrete structure, negating the passive heat storage potential of the thermal mass. Thus, these adaptive behaviors prove that the 'performance gap' is driven not only by envelope deficiencies but by necessary user modifications that fundamentally alter the building's physics (Appendix E, Figure 42).

Similarly, the survey on summer adaptations illustrates how residents in both zones are forced to actively compensate for the lack of integrated solar protection, though the nature of their intervention differs. In Aydın, the high response rate (73.5%) highlights a critical functional trade-off: to combat chronic overheating, residents sacrifice visual comfort and daylight by keeping curtains permanently closed, effectively rendering the unshaded window a thermal liability rather than an asset. Conversely, Yozgat exhibits a similarly high intervention rate (65.2%) despite the low reported need for mechanical cooling. This apparent contradiction confirms that while summer discomfort in the continental climate is transient and manageable through passive behaviors (e.g., airflow management) rather than active cooling, it still demands constant user vigilance. Thus, in both cases, the absence of fixed shading elements forces occupants to manually regulate the envelope to maintain habitability (Appendix E, Figure 43).

52.8% of respondents in the Aydın TOKİ housing complex reported experiencing thermal discomfort in the living room, attributing this primarily to excessive indoor heat during the summer months. Given that the living room is the primary space for social interaction, leisure, and family activities, occupants spend the majority of their time there. Consequently, they appear to exhibit heightened sensitivity to temperature fluctuations and overheating in this area compared to transient spaces such as bedrooms or kitchens. Conversely, in the Yozgat TOKİ housing complex, 47.8% of respondents identified the living room as the coldest space in the dwelling, citing insufficient heating and heat loss through the façades as the primary causes. Similar to

the Aydın case, the living room in Yozgat serves as the central hub for household activity, which increases user sensitivity to thermal conditions. Although the nature of the discomfort differs significantly—manifesting as overheating in Aydın versus cold stress in Yozgat—both surveys concur that the living room is perceived as the least thermally comfortable space within the dwelling (Appendix E, Figure 44).

5.2.2. Visual Comfort & Daylight Perception

Survey results indicate that overall daylight access is perceived positively by a considerable share of residents in both housing complexes, though the intensity of satisfaction varies. In the Aydın TOKİ complex, 41.7% of participants selected the highest possible rating (5 on a 5-point scale) when asked if their apartments received sufficient natural light throughout the day. This reflects a strong consensus regarding high daylight availability and visual comfort. In the Yozgat TOKİ complex, responses suggest generally satisfactory daylight conditions, albeit with slightly more variation. The majority of Yozgat respondents (39.1%) selected a rating of "4" on the five-point scale. While this signifies that most dwellings receive adequate sunlight for the majority of daylight hours, the satisfaction levels are slightly more moderate compared to the "strong satisfaction" reported in Aydın (Appendix E, Figure 45).

While general satisfaction with daylight availability was high in Aydın, responses regarding the necessity of artificial lighting during daytime hours were notably polarized. A distinct divergence emerged in the data: 22.2% of residents reported no need for artificial lighting (rating 1), whereas 27.8% indicated a relatively high dependency (rating 4). This discrepancy can largely be attributed to differences in apartment orientation and façade exposure; south-facing units benefit from ample solar access, while north-facing dwellings frequently experience insufficient daylight levels. In contrast, the Yozgat TOKİ complex exhibited a more moderate pattern regarding artificial lighting dependency. When evaluating whether insufficient daylight necessitated supplemental lighting, the largest share of respondents (39.1%) selected a median rating of "3". This indicates that while daylight levels are generally functional, specific zones within the apartments require artificial lighting intermittently. Similar to the Aydın case, these results suggest that variations in

building orientation and apartment layout play a significant role in determining daylight availability across the complex (Appendix E, Figure 46).

In order to regulate solar gains and enhance visual comfort, a substantial majority of residents in the Aydın TOKİ complex (83.3%) reported making personal adjustments to their living space. These adaptive behaviors included the operation of curtains and roller blinds, the installation of window films, and the rearrangement of furniture to maximize daylight penetration. A similar trend was observed in the Yozgat TOKİ complex, where 78.3% of participants reported engaging in adaptive strategies to manage solar exposure and optimize lighting comfort. The adjustments cited mirrored those in Aydın, consisting primarily of curtain and blind operation, furniture rearrangement, and the use of auxiliary shading devices or films (Appendix E, Figure 47).

5.2.3. Indoor Air Quality & Ventilation

Regarding indoor air quality and ventilation, survey responses indicate a moderate level of satisfaction among Aydın residents. When asked to evaluate the adequacy of their ventilation systems (whether natural or mechanical) in meeting daily needs, exactly 50% of participants selected the mid-scale value (3 on a 1–5 scale). A similar pattern of moderate satisfaction was observed in the Yozgat TOKİ complex. When evaluating ventilation performance, 47.8% of respondents selected a rating of "3" on the five-point scale. This indicates that while airflow is generally deemed adequate, it falls short of meeting full comfort expectations. In the context of Yozgat, this result is likely influenced by climatic constraints; specifically, low outdoor temperatures during the heating season limit the frequency of window operation, thereby restricting natural ventilation rates and perceived air quality (Appendix E, Figure 48).

In addition to ventilation mechanics, lifestyle factors—specifically the presence of internal pollutant sources—were analyzed to contextualize indoor air quality performance. In the Aydın TOKİ complex, 66.7% of participants reported that smoking does not occur within their households. This significantly mitigates the load on ventilation systems, highlighting that the need for fresh air circulation is driven primarily by metabolic CO₂ removal and thermal regulation rather than smoke clearance. This was even more pronounced in the Yozgat TOKİ complex, where a

significant 87% of households were reported as non-smoking. The high prevalence of smoke-free environments in Yozgat suggests that the previously reported "moderate" satisfaction with air quality is not a result of lifestyle-generated pollutants, but rather underscores the limitations of the natural ventilation strategy itself (Appendix E, Figure 49).

5.2.4. Material Performance & Building Envelope

The survey revealed widespread concerns regarding the long-term integrity and performance of the building materials in the Aydın TOKİ complex. When queried about the presence of visible defects in the building envelope—specifically cracks, water infiltration, or surface deterioration—63.9% of respondents answered affirmatively. This substantial figure identifies material degradation as a systemic issue within the housing complex, rather than an isolated occurrence. In the Yozgat TOKİ complex, reports of envelope degradation were even more prevalent. Despite qualitative indications that specific moisture-related pathologies (such as mold) may be less common than in other climatic regions, 78.3% of respondents confirmed observing visible defects such as cracks, leaks, or signs of aging. This high incidence rate—exceeding that of Aydın—suggests that the building envelope in Yozgat faces significant durability challenges, potentially exacerbated by the harsher climatic conditions and thermal stresses typical of the region (Appendix E, Figure 50).

In the Aydın TOKİ complex, moisture-related pathologies were reported with alarming frequency, exceeding even the rates of structural defects. A significant 73.5% of participants indicated the presence of mold growth, surface darkening, or dampness on interior surfaces. These issues were predominantly localized near thermal bridges, specifically external walls, window perimeters, and ceiling corners, suggesting substantial failures in insulation continuity or humidity control. The Yozgat TOKİ complex exhibited a much lower incidence of interior moisture problems, despite the high prevalence of external envelope defects noted previously. While structural wear was often observed on exterior wall surfaces and balconies—indicating potential weaknesses in construction quality or weathering—this did not translate into internal dampness for the majority of residents. When queried about mold, darkening, or dampness on interior surfaces, 65.2% of participants reported no such occurrences.

This divergence underscores that while the building envelope in Yozgat is physically degrading, the indoor environment remains comparatively dry, likely due to the lower ambient humidity characteristic of the region's climate (Appendix E, Figure 51).

5.2.5. Comparative Evaluation of Survey Results

The comparative evaluation between Aydın and Yozgat reveals distinct variations in user experiences that reflect the climatic and environmental differences between the two regions. In both cases, the demographic profiles were dominated by middle-aged residents, most of whom were women who spend extended hours at home. This ensured that the responses were based on consistent daily observations of comfort and environmental quality. However, while both groups reported actively adapting their living conditions, the motivations and seasonal challenges they faced differed significantly due to regional climate contrasts.

Thermally, the 'Living Room' serves as the prime indicator of this typological incompatibility. In Aydın, the standardized large apertures turn this high-occupancy zone into a 'heat trap,' overwhelmed by solar ingress due to insufficient shading. Conversely, in Yozgat, the exact same spatial configuration transforms the room into a primary source of 'heat loss,' where large glazing areas compromise the thermal buffer against the cold. This paradox confirms that a generic window-to-wall ratio cannot function successfully in both Zone 1 and Zone 4; what is architecturally 'generous' in the cold climate becomes 'excessive' in the hot climate.

A similar dichotomy is observed in Visual Comfort and Air Quality. Aydın exhibits a polarized performance—south-facing units suffer from glare while north-facing ones lack daylight—proving the inadequacy of static façades in managing intense solar angles. In terms of ventilation, residents in both zones face a 'ventilation paradox': to maintain thermal comfort, they are forced to keep windows closed during peak seasons (summer in Aydın, winter in Yozgat), thereby compromising indoor air quality. This suggests that reliance on natural ventilation alone, without climate-specific passive pre-conditioning (like cross-ventilation or thermal buffering), is insufficient for mass housing.

The structural identicality has led to divergent material failures: Aydın's humidity drives biological degradation (mold/condensation), while Yozgat's freeze-thaw cycles drive physical degradation (cracks/fissures). Thus, the survey concludes that the 'performance gap' is not merely a simulation error, but a physical reality; the standardized application of materials and details across distinct climatic zones inevitably leads to accelerated deterioration and compromised habitability



CHAPTER 6: SIMULATION STUDY

6.1. Methodology and Modeling Assumptions

6.1.1 Building Energy Simulation

Building Energy Simulation (BES) is fundamental to low-energy design. Its methodological roots trace back to the response factor algorithms of the 1920s and 1950s, which HVAC engineers later adopted for cooling load calculations (Glotzer, 2011). The field advanced significantly when Kusuda integrated environmental variables, such as solar radiation, into single-zone analysis (Jenkins, 2011). In the modern era, the convergence of BEM with Building Information Modeling (BIM), alongside stricter regulatory frameworks, points to the discipline's continued expansion (Jenkins, 2011). Today, BEM offers high predictive capability, providing a scientific alternative to traditional experimentation for optimizing both physical building behavior and occupant satisfaction (Glotzer, 2011).

Over the last few decades, Building Energy Simulation (BES) has evolved into a fundamental decision-support tool for the AEC industry, particularly in thermal analysis and pre-construction performance assessment. As highlighted by Hien et al. (2003), the integration of simulation workflows into the collaborative design process is essential for verifying design decisions and achieving sustainability goals in modern construction.

By analyzing critical variables such as the thermal envelope, solar exposure, and fenestration, simulation tools allow design teams to virtually visualize and comprehend the building's performance prior to construction, ensuring optimized design solutions (Hensen et al., 2004).

In light of this general framework, this study building energy simulations were conducted to assess how standardized TOKİ apartment units respond to distinct climatic conditions in Aydın and Yozgat. The simulation phase focused on key passive design variables using a parametric modeling workflow in Grasshopper. By applying identical building geometry across both locations, the simulations enabled a controlled comparison of climatic responsiveness based solely on environmental variation. The outputs provided quantitative benchmarks for daylight availability and thermal

comfort, forming the basis for subsequent integration with occupant survey data in the overall evaluation framework.

6.1.2 Simulation Approach and Tools

In this study, a parametric simulation workflow was adopted to conduct building performance analyses and to examine how design variables influence indoor environmental conditions. As the primary platform for the simulations, the algorithmic modeling interface Grasshopper, integrated within the Rhinoceros 3D modeling software, was utilized. The core computational engine employed is Grasshopper, an algorithmic modeling interface that operates via visual data flow diagrams. Unlike traditional static modeling, this approach allows for the dynamic and iterative manipulation of building geometry and environmental constraints, as defined by Roudsari and Pak (2013).

To manage the simulation process, process climate data, and ensure interaction with analysis engines, the open-source plugins Honeybee and Ladybug, operating within the Grasshopper environment, were employed. Honeybee serves as an interface that takes the generated parametric building model, material assignments, and climate data, converting them into the format of internationally validated simulation engines. Within the scope of this study, two fundamental computation engines, considered industry standards depending on the analysis type, were utilized:

- *Daylight Simulation:* The Radiance simulation engine was utilized to assess the visual comfort and daylight performance of the reference units. Recognized in the literature for its high precision, Radiance models light behavior in a physically accurate manner using the "backward ray-tracing" technique. Through this engine, illuminance levels were analyzed using Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI) metrics across both annual and specific seasonal (summer and winter) periods.
- *Thermal Comfort Simulation:* The EnergyPlus simulation engine was used to determine the dynamic thermal behavior of the building, heating-cooling energy loads, and user comfort metrics. EnergyPlus is considered one of the most advanced tools in the field of building energy modeling, particularly due to its capability to calculate dynamic thermal interactions and complex

building systems. Honeybee interface, the computational power of the EnergyPlus engine has been transferred to the parametric design environment.

Given the extensive graphical nature of spatial daylight analysis, and to maintain a balanced narrative with the thermal performance section, the detailed zonal maps and full graphical outputs are provided in Appendix G- Useful Daylight Illuminance (UDI) Distribution. Consequently, the comparative evaluation in this chapter focuses on the synthesized percentage values of UDI-a and UDI-e to highlight the critical trade-offs between daylight access and visual discomfort.

To conduct the simulations under realistic boundary conditions, hourly weather data for the provinces of Aydın and Yozgat were obtained in EPW (EnergyPlus Weather) format. These data were imported into the simulation environment using the Ladybug tool; critical environmental parameters such as dry-bulb temperature, solar radiation, humidity, and wind speed were used as inputs in the analyses (Roudsari & Pak, 2013).

6.1.3 Base Case Model Parameters

In this study, the processes of generating the simulation model and conducting the analysis were executed through a parametric algorithm established within the Rhinoceros/Grasshopper environment, rather than utilizing static modeling. This parametric approach enabled the automated generation of building geometry, the flexible manipulation of design variables (such as wall thicknesses, window-to-wall ratios, etc.), and the rapid execution of iterative analyses. In the initial phase of the modeling process, the exterior walls, window openings, and interior partition walls were defined as parametric surfaces and masses via the Grasshopper algorithm, based on the building's floor plan scheme.

To ensure a valid and consistent comparison between different climatic regions such as Aydın and Yozgat, the analyzed building model was standardized. Considering that the existing TOKİ implementations in Yozgat consist of 2+1 unit types, while Aydın features both 2+1 and 3+1 options, the 2+1 apartment type, being the common typology in both regions, was selected as the reference (base case) to maintain the consistency of the comparative analysis.

Standardization of the model in this manner guarantees that the performance differences observed in the simulation results stem entirely from climatic variations and the applied passive design strategies, rather than geometric variables.

Prior to the main simulation phase, a comprehensive preliminary assessment process was conducted to confirm the geometric consistency and semantic accuracy of the model. At this stage, the model was inspected to verify whether it possessed a "watertight" geometry, whether the thermal zones were correctly defined according to their functions, and whether the material assignments were consistent. To optimize the computational load of the simulation, architectural details with no direct impact on thermal performance (such as door handles, fine decorative elements, etc.) were excluded from the model. During the modeling process, rooms were defined with distinct thermal zone names based on their functions and were color-coded to ensure distinguishability on the analysis screen.

Following the completion of modeling and zoning operations on the floor plan plane, the building floor height parameter was input into the system to generate the volumetric model, thereby rendering the structure ready for simulation. In alignment with the original architectural project files, the north orientation indicated in the official design documents was used as the reference direction throughout the simulation process.

The structural and geometric parameters used to construct the simulation model are summarized in Table 2. As mentioned before the building typology examined within the scope of this study consists of standard residential mass housing projects produced by TOKİ (Housing Development Administration of Turkey). To ensure the consistency of the comparative analysis, the unit configuration was fixed as a 2+1 apartment type.

In the table, Gross Floor Area refers to the total area within the exterior wall contours of the unit. In contrast, Conditioned Floor Area represents the net volume where active heating and cooling loads are calculated by the simulation engine; this calculation excludes balconies or unheated service shafts. All other physical characteristics of the model, such as floor heights, and the number of thermal zones, are detailed in the Table 2.

Table 2. Geometric characteristics of the standardized base case model.

PARAMETER	DESCRIPTION / VALUE
Building Typology	Residential TOKİ Building
Unit Configuration	2+1 Apartment Unit
Gross Floor Area	1.582,8 m ²
Conditioned Floor Area	976 m ²
Floor-to-Ceiling Height	2.91 m
Total Building Height	12.84 m
Number of Stories	5 Stories
Number of Thermal Zones	4 Zones
Orientation (Main Façade)	North-South Axis

Finally, the site context was integrated into the simulation environment to account for the critical impact of mutual shading on daylight and thermal loads. The specific site layouts were modeled as massing volumes—comprising 7 blocks (5 stories) in Aydın and 6 blocks (4 stories) in Yozgat. For the detailed performance analysis, a single 'representative' block was selected within each complex, while the surrounding structures were defined as obstruction objects (Figure 16 and Figure 17). Although it is acknowledged that the precise shading profile may exhibit minor variations depending on a block's specific location within the site plan, this representative approach ensures that the overarching impact of the urban texture is captured. This inclusion is vital to prevent the overestimation of solar gain and daylight levels that would inevitably occur in an isolated building analysis.

All key model inputs—ranging from climate files and zoning logic to shading context and sensor settings—are summarized in Appendix F- Simulation Input Parameters for reference.

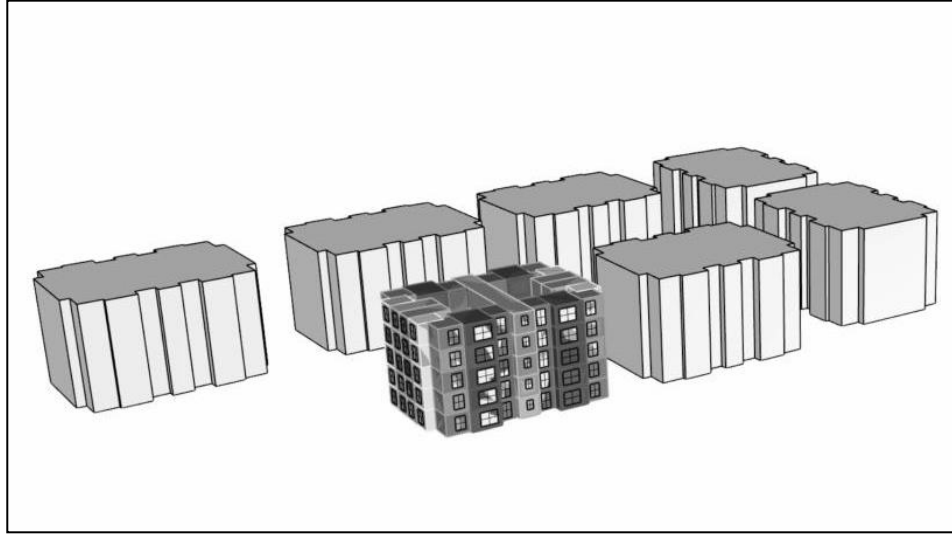


Figure 16. Context site model of the Aydın TOKİ settlement, illustrating the 5-story reference block and the surrounding shading obstacles (7 blocks).

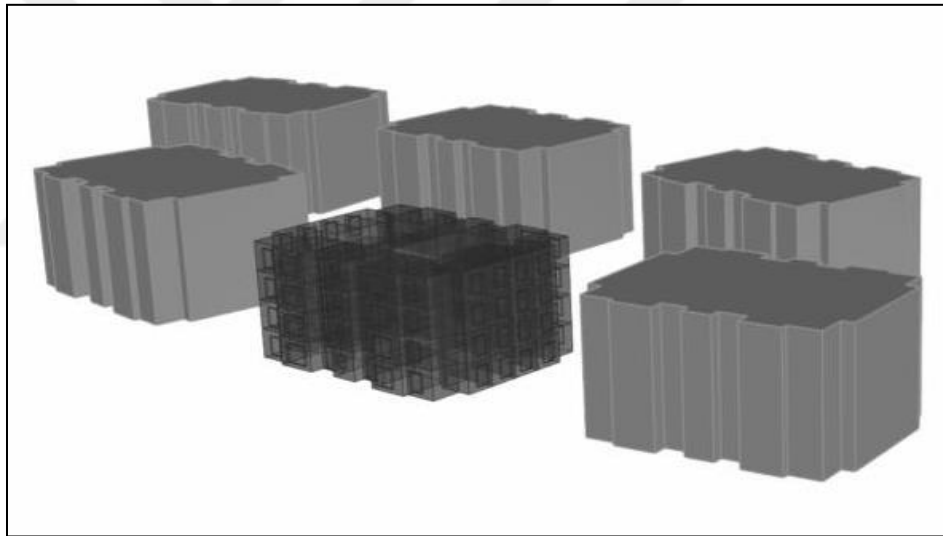


Figure 17. Context site model of the Yozgat TOKİ settlement, illustrating the 5-story reference block and the surrounding shading obstacles (6 blocks).

The parametric algorithm, which constitutes the backbone of the simulation process, was constructed within a visual programming environment where not only the building geometry but also the daylight analysis parameters (Radiance engine settings, test grids, and sensor points) were defined. This flow diagram, integrating Honeybee and Ladybug components, ensures the seamless transfer of geometric data to the simulation engines (Radiance) and establishes a reproducible systematic framework for the analyses.

6.1.4. Evaluation Metrics and Performance Criteria

To assess the building performance objectively, this study employs a set of dynamic simulation metrics focusing on two primary domains: visual comfort (daylight availability) and thermal comfort (physiological stress). These metrics transcend static snapshots, evaluating performance over time to capture the seasonal variations inherent in the climates of Aydın and Yozgat. For the visual comfort assessment, a dual-metric approach was adopted to balance 'quantity' with 'quality':"

- Daylight Autonomy (DA): "Selected as the primary measure for daylight sufficiency, DA quantifies the percentage of occupied hours during which a sensor point receives illuminance above a specified threshold. Aligning with international standards such as IES LM-83-12 and LEED v4, the threshold for this study was set at 300 lux. This value represents the minimum illuminance required to perform general domestic activities (e.g., reading, cooking) without reliance on artificial lighting. Thus, any point achieving this level is considered 'autonomous' for that hour."
- Useful Daylight Illuminance (UDI): "While DA assesses sufficiency, it fails to identify visual discomfort caused by excessive brightness. To address this limitation, UDI was integrated to evaluate the quality of daylight. Based on the foundational framework by Nabil and Mardaljevic (2006), illuminance levels are categorized into three distinct ranges to identify useful light versus potential hazards:

UDI-u (<100 lux): Insufficient daylight, requiring artificial support.

UDI-a (100–2000 lux): The 'Autonomous' range, representing ideal conditions where daylight is sufficient without causing discomfort.

UDI-e (>2000 lux): The 'Exceeded' range. Values above this limit indicate an oversupply of daylight, posing significant risks for glare and, particularly in the hot climate of Aydın, solar overheating.

The analysis visualizations utilize a percentage-based color scale to illustrate these metrics. Blue tones (0% - 20%) represent "dark zones" where natural lighting is

insufficient for the majority of the year. Yellow and Orange tones (40% - 70%) indicate acceptable and balanced lighting levels. Red tones (80% - 100%) signify areas receiving high levels of daylight throughout almost the entire year. However, interpretation of these high values is context-dependent; in the hot-humid climate of Aydın, high ratios in red zones are interpreted not just as excellent daylight availability, but also as indicators of potential overheating and glare risks.

While annual simulations provide a comprehensive overview of the general daylight availability, they often rely on averaged data that may obscure critical performance variations occurring at seasonal extremes. To address this limitation and obtain a more granular understanding of the building's response to changing solar angles, a Seasonal Daylight Analysis was conducted.

The analysis focuses on two distinct periods representing the climatic extremes:

- Summer Period (June - August): Representing the months with the highest solar altitude and longest daylight hours.
- Winter Period (December - February): Representing the months with the lowest solar altitude and shortest daylight hours.

To evaluate thermal comfort, the study utilizes the Universal Thermal Climate Index (UTCI). Unlike simple dry-bulb temperature measurements, UTCI provides an assessment of the "felt" or equivalent temperature, offering a more accurate representation of human physiological response to the thermal environment.

The UTCI calculation integrates four key meteorological and physical parameters:

1. Air Temperature
2. Mean Radiant Temperature: Accounting for heat radiated from surfaces.
3. Relative Humidity
4. Air Velocity

For this study, UTCI values were calculated and visualized as "Comfort Maps" using the Ladybug, Honeybee and EnergyPlus plugins within the Grasshopper parametric design environment. The resulting maps categorize the thermal environment based on stress levels (degrees Celsius), ranging from cold stress to heat stress. This approach

allows for a spatial understanding of where and when occupants are likely to experience thermal discomfort within the reference units.

6.2. Daylight Simulation Results

6.2.1. Annual Daylight Autonomy (DA) Analysis

Daylight Autonomy (DA) measures the percentage of occupied hours throughout the year where the minimum illuminance threshold is met by daylight alone. To provide a comprehensive evaluation, this study analyzes the building performance considering both annual and seasonal variations. This section presents a comparative evaluation of the Annual DA performance for the reference housing blocks in Aydın and Yozgat (Figure 18). While the spatial distribution of daylight appears visually similar due to the identical building typology, the environmental implications of these results differ significantly between the two distinct climatic zones.

In both Aydın and Yozgat, the simulation maps reveal a distinct "saturation zone" along the building perimeter. Living rooms and bedrooms located on the exterior façade are rendered in dark red with a maximum legend value of 100, indicating that these spaces receive daylight above the threshold for nearly 100% of the occupied hours.

However, the interpretation of this high daylight availability varies by context:

1. *In Aydın (Cooling-Dominated):* The saturation of daylight suggests an excessive admission of solar radiation. While visual levels are high, this correlates with a risk of overheating and potential visual discomfort (glare), reinforcing the earlier climatic analysis that identified a need for shading.
2. *In Yozgat (Heating-Dominated):* The same high DA values are largely advantageous. In this cold climate, the extensive daylight penetration implies beneficial passive solar heat gain during winter months, contributing to the reduction of heating loads. Nevertheless, the risk of glare remains a concern that must be managed without blocking the useful heat gain.
3. *Impact of Site Layout (Contextual Shading):* Both simulations incorporate the surrounding TOKİ housing blocks to measure the impact of the site layout. This effect is visible as localized blue and yellow patches interrupting the red

saturation zones on the façades. These irregularities confirm that neighboring buildings create specific shade masks, obstructing solar access during certain hours. This demonstrates that the daylight performance is not solely a function of the building design but is heavily influenced by the density and orientation of the master plan settlement.

4. *Deep Plan Limitations (The Inner Core):* A consistent failure is observed in the building's core across both locations. The circulation areas located along the central axis remain uniformly blue with a value of 0. This indicates that the depth of the plan prevents natural light penetration entirely, rendering these zones dependent on artificial lighting throughout the year, regardless of the external climatic conditions or solar potential.

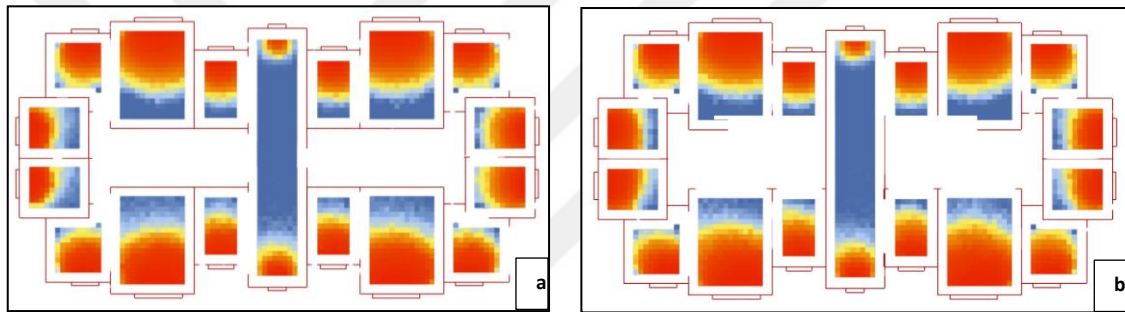


Figure 18. Annual Daylight Autonomy (DA) distribution analysis of the Aydın (a) & Yozgat (b) floor plans of reference blocks.

Ultimately, the daylight simulations expose the fundamental rigidity of the standardized typology. While the DA distribution maps appear graphically identical for both cities, their architectural implications are contradictory: the extensive high-DA zones act as a 'thermal liability' in Aydın (overheating risk) but a 'passive asset' in Yozgat (winter heating). The qualitative UDI analysis clarifies this contrast (Appendix G, Figure 53), revealing that while Aydın suffers from 'directional asymmetry' and obstructed southern gain due to site density, Yozgat exhibits 'balanced resilience' with uninterrupted solar access. Despite these perimeter variations, the complete absence of daylight in the service core (0 lux) across all simulations reveals a universal structural failure. Thus, the analysis confirms that the 'one-size-fits-all' deep-plan design creates dangerous excesses in the hot zone while failing to illuminate the core in any climatic context.

In order to provide a clearer comparative analysis, the simulation output values are presented on a standardized 0-100 scale. As defined in Table 3, this scale is direct, where a score of 100 represents the maximum performance threshold (full saturation) in the analyzed context.

Table 3. Color scale interpretation and performance criteria for Annual Daylight Analysis.

Performance Level / Color Code	Legend Original Value Range	Legend Normalized Score Range	Performance Interpretation
Low (Dark Blue)	0 - 20	0 - 20	Significant reliance on artificial lighting is required.
Medium - Low (Light Blue)	21 - 40	21 - 40	Supplemental lighting is needed for most tasks.
Medium (Yellow)	41 - 60	41 - 60	Balanced use of natural and artificial light.
Medium – High (Orange)	61 - 80	61 - 80	Visual comfort is achieved for extended periods.
High (Red)	81 - 100	81 - 100	Maximizes natural light potential (glare control may be noted).

6.2.2. Seasonal Daylight Autonomy (DA) Analysis

The summer period analysis (June–August) evaluates daylight performance under the conditions of peak solar altitude and intensity. While the simulation maps for both cities display visually similar high saturation along the perimeter (Figures 19), the environmental consequences of this availability differ fundamentally due to the opposing climatic priorities of the two regions:

1. *In Aydın (Cooling-Dominated)*: The saturation of the perimeter zones (Red zones: 100% DA) represents a critical thermal vulnerability. In this hot climate,

the continuous high-intensity band indicates that shading from neighboring buildings is ineffective against the high solar altitude. Consequently, the building envelope acts as a heat source, necessitating external shading devices to prevent overheating. However, the rapid reduction of daylight penetration towards the rear ("Deep Zone Relief") acts as a slight advantage here; it suggests that excessive solar radiation is concentrated at the perimeter rather than penetrating deep into the building's thermal mass.

2. *In Yozgat (Heating-Dominated):* While the perimeter saturation is identical, the thermal penalty is less severe. The primary risk in Yozgat shifts from overheating to visual discomfort (glare). The high illuminance levels require management for visual tasks, but the associated thermal load is not as detrimental as in the Aydın context. Additionally, a distinct directional variance is observed: South-facing units maintain high-intensity daylight deeper into the room, whereas North-facing units rely primarily on diffuse light restricted to a narrow strip, minimizing direct radiation exposure.
3. *Daylight Gradient & Penetration Profile:* Both simulations exhibit a characteristic positive daylight gradient, where saturation transitions from red (perimeter) to yellow and eventually to blue tones (core). This confirms that regardless of location, the daylight sufficiency is heavily weighted towards the façade line. While this gradient provides necessary illumination for living areas near the window, the sharp drop-off reinforces the dependency on artificial lighting for the rear zones of the deep-plan typology.

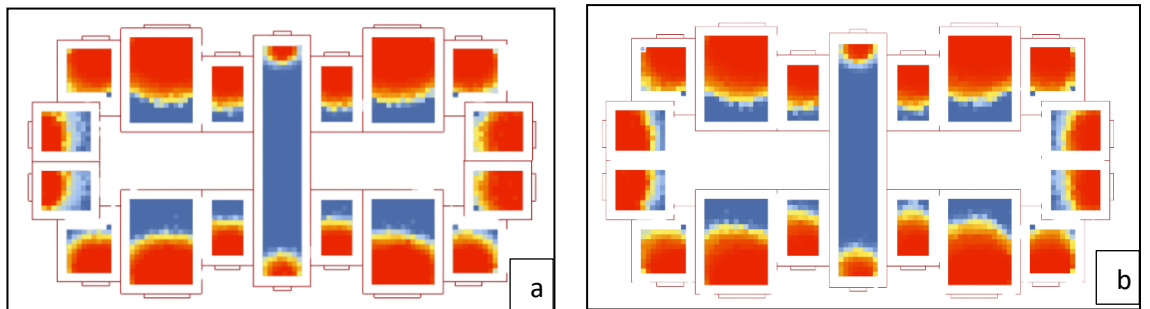


Figure 19. Seasonal (summer) Daylight Autonomy (DA) distribution analysis of the Aydın (a) and Yozgat (b) floor plans of reference blocks.

The summer analysis exposes the critical limitations of relying on 'contextual shading' during peak solar months. Generally, the high solar altitude renders neighboring

shadows ineffective, transforming perimeter windows in Aydın into 'thermal bridges' that jeopardize the cooling strategy. The UDI analysis (Appendix G, Figure 54) confirms this vulnerability through a 'qualitative inversion': intense radiation at the window line exceeds useful limits (>2000 lux), creating severe glare risks rather than functional daylight. A notable exception is the West facade in Aydın, where a site-specific anomaly creates beneficial shading, acting as that blocks harsh afternoon sun. Conversely, Yozgat translates this high solar exposure into 'controlled efficiency,' avoiding glare risks while maintaining high useful daylight scores, though it suffers from a sharper drop in penetration depth towards the rear.

In order to provide a clearer comparative analysis, the simulation output values (originally ranging from 0 to 25) were normalized to a standard 0-100 scoring system. As shown in Table 4, the maximum value of 25 corresponds to a score of 100.

Table 4. Color scale interpretation and performance criteria for Summer DA Daylight Illuminance (DA) Analysis.

Performance Level / Color Code	Legend Original Value Range	Legend Normalized Score Range	Performance Interpretation
Low (Dark Blue)	0 - 5	0 - 20	Significant reliance on artificial lighting is required.
Medium - Low (Light Blue)	5.1 - 10	21 - 40	Supplemental lighting is needed for most tasks.
Medium (Yellow)	10.1 - 15	41 - 60	Balanced use of natural and artificial light.
Medium – High (Orange)	15.1 - 20	61 - 80	Visual comfort is achieved for extended periods.
High (Red)	20.1 - 25	81 - 100	Maximizes natural light potential (glare control may be noted).

The winter period analysis (December–February) represents the critical design scenario for heating-dominated performance. Fundamentally, this season inverts the performance criteria: unlike the summer analysis, where high daylight autonomy was a thermal risk, here it is interpreted as a vital 'passive asset' contributing to both visual comfort and essential solar heating (Figure 20).

1. **South Façade Resilience:** The South-facing units demonstrate exceptional resilience across both climatic zones. The simulation maps reveal high saturation levels (Red/Orange zones: 80–100% DA) penetrating deep into the floor plan. This confirms that the low-angle winter sun successfully bypasses the window lintels. While this deep penetration contributes to thermal comfort in Aydın's mild winter, for Yozgat, it acts as a critical primary heat source, significantly offsetting the heavy active heating loads required in the severe continental climate.
2. **North Façade Deficiency:** A sharp performance drop on the North façades exposes the limitations of the building form when deprived of direct sun. In both Aydın and Yozgat, units that were saturated in summer turn largely "Blue" (0–20% DA). This indicates that the diffuse skylight intensity alone is insufficient to meet the 300 lux threshold during winter months, forcing a reliance on artificial lighting for the majority of occupied hours regardless of the location.
3. **Impact of Context:** Unlike the summer scenario, the site layout exerts a detrimental impact during winter. On the East and West wings, a "steep daylight gradient" is observed, characterized by a rapid transition from window (Orange) to rear wall (Blue). This suggests that neighboring buildings—casting significantly longer shadows due to the low solar altitude—effectively obstruct solar access during critical morning and afternoon hours, severely limiting the effective daylight zone to the immediate perimeter.

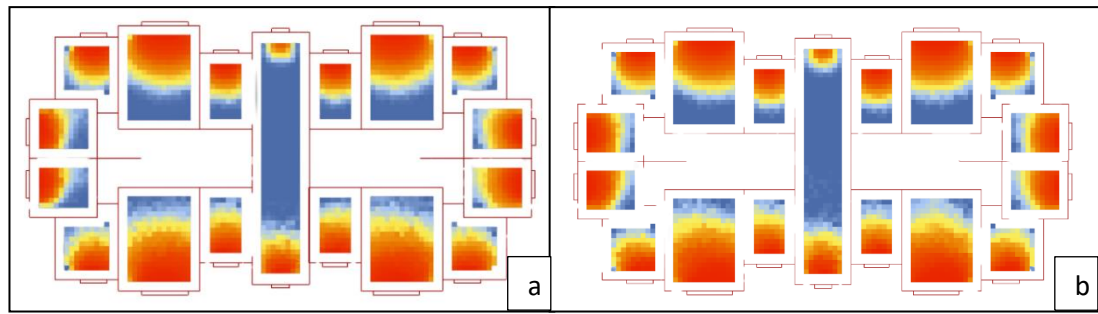


Figure 20. Seasonal (winter) Daylight Autonomy (DA) distribution analysis of the Aydın (a) and Yozgat (b) floor plans of reference blocks.

Ultimately, the interaction between Daylight Autonomy (DA) and UDI metrics reveals a distinct 'Performance Polarization' dictated by the site layout. The DA results expose a 'Double Disadvantage': neighboring blocks cast long shadows on the East and West wings exactly when solar gain is needed, strictly confining daylight availability to the window perimeter. Conversely, the UDI analysis (Appendix G, Figure 55) highlights the South façade as the architectural ideal, confirming an 'Optimal Passive Scenario.' Unlike the glare-prone summer condition, the low-angle winter sun penetrates deep into the southern rooms within the 'useful' range (100–2000 lux). Thus, while the South orientation successfully maximizes passive heating without visual discomfort, the remaining orientations (North/East/West) fail to capture beneficial solar energy, leaving the majority of the building envelope dependent on active systems.

In order to provide a clearer comparative analysis, the simulation output values (originally ranging from 0 to 21) were normalized to a standard 0-100 scoring system. As shown in Table 5, the maximum value of 21 corresponds to a score of 100.

Table 5. Color scale interpretation and performance criteria for winter DA Analysis.

Performance Level / Color Code	Legend Original Value Range	Legend Normalized Score Range	Performance Interpretation
Low (Dark Blue)	0.00 – 4.20	0 - 20	Significant reliance on artificial lighting is required.

Table 5 (continued). Color scale interpretation and performance criteria for winter DA Analysis.

Medium - Low (Light Blue)	4.21 – 8.40	21 - 40	Supplemental lighting is needed for most tasks.
Medium (Yellow)	8.41 – 12.60	41 - 60	Balanced use of natural and artificial light.
Medium – High (Orange)	12.61 – 16.80	61 - 80	Visual comfort is achieved for extended periods.
High (Red)	16.81 – 21.00	81 - 100	Maximizes natural light potential (glare control may be noted).

6.3. Thermal Comfort Simulation Results

Following the assessment of visual comfort, this section focuses on the thermal performance of the selected case studies. As defined in the methodology, thermal comfort simulations are conducted to evaluate the indoor environmental quality and determine the percentage of time that conditions remain within acceptable limits for occupant satisfaction. To provide a detailed understanding of the building's behavior, the analysis considers both annual comfort performance and seasonal variations, specifically highlighting the distinct responses during critical winter and summer periods. The results are structured below, beginning with the annual performance analysis.

6.3.1. Annual Thermal Comfort (UTCI) Analysis

The comparative analysis of the annual UTCI distribution for Aydın and Yozgat (Figure 21) reveals distinct thermal behaviors despite the apparent similarities in their "no thermal stress" classification.

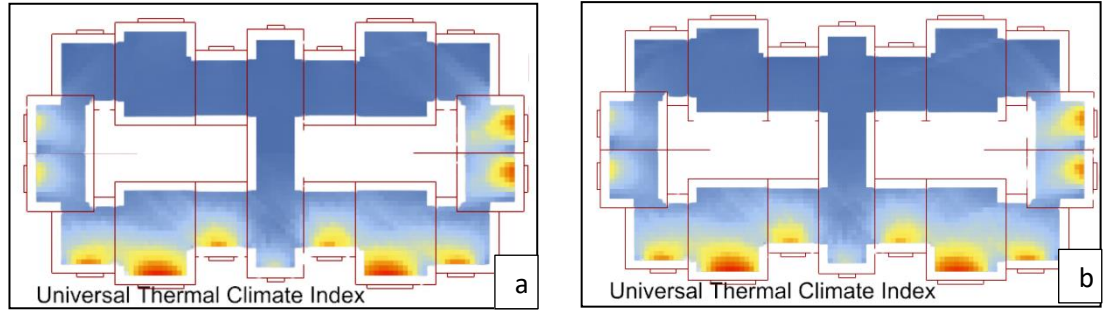


Figure 21. Annual Universal Thermal Climate Index (UTCI) distribution analysis of the Aydın (a) and Yozgat (b) floor plans of reference blocks.

1. *Global Comfort Levels & the 'Climatic Offset':* Both simulation cases indicate a thermally stable environment where annual average equivalent temperatures fall comfortably within the UTCI "no thermal stress" zone (9°C to 26°C). However, a distinct baseline shift is observed in the cumulative thermal energy balance. While Aydın maintains a higher average band of 22.39°C to 23.19°C reflecting its Mediterranean characteristics, Yozgat's profile shifts lower, settling between 20.77°C and 21.62°C . Although this difference of approximately 1.5°C appears numerically subtle, it signifies a fundamental divergence in the underlying climatic baselines.
2. *Spatial Distribution: Envelope vs. Orientation:* Although both floor plans exhibit spatial homogeneity with internal temperature variations remaining below 1.0°C , the drivers of these gradients differ fundamentally. In Aydın, the variation is primarily envelope-driven; zones adjacent to the Southern and Eastern façades show slightly higher UTCI values ($\sim 23.1^{\circ}\text{C}$) due to general solar interaction, while the central core remains cooler ($\sim 22.4^{\circ}\text{C}$), acting as a thermal buffer against external loads. Conversely, Yozgat demonstrates a sharper, orientation-driven dichotomy. A clear contrast is observed between the South-facing zones, which achieve the highest UTCI values via passive solar gain, and the North/Core zones which linger at the lower end of the spectrum ($\sim 20.8^{\circ}\text{C}$). This confirms that in the heating-dominated context of Yozgat, the southern orientation acts as a critical passive heat source, whereas Aydın's profile is influenced by broader envelope exposure.

Fundamentally, the annual analysis presents a picture of 'Deceptive Stability.' The averaging of seasonal extremes results in a seemingly comfortable indoor environment for both cities, masking the severe overheating risks in summer and freezing risks in winter. However, the spatial mapping reveals a critical divergence: in Yozgat, thermal comfort is strictly dependent on the South orientation (passive gain), whereas in Aydın, it is driven by the overall envelope exposure. This suggests that while the annual averages are similar, the architectural mechanisms required to maintain them—heating for Yozgat and cooling for Aydın—are fundamentally opposing.

6.3.2. Seasonal Thermal Comfort (UTCI) Analysis

The Summer UTCI analysis (June–August) isolates the most critical period for cooling performance. While the annual averages suggested general comfort, the seasonal breakdown reveals that the reference building operates under vastly different safety margins in Aydın and Yozgat (Figure 22).

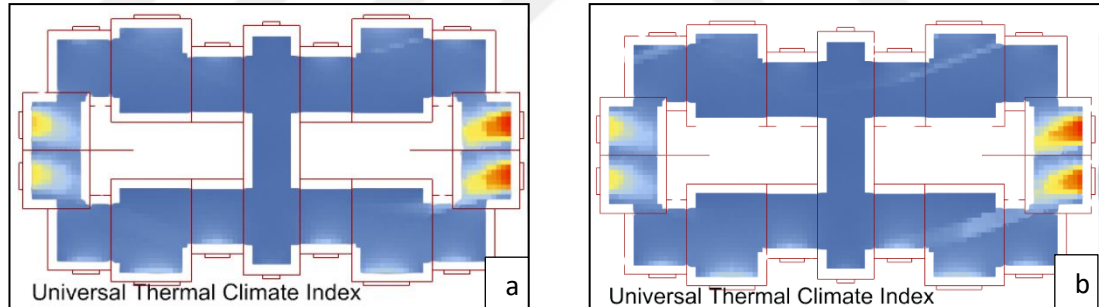


Figure 22. Seasonal (summer) Universal Thermal Climate Index (UTCI) distribution analysis of the Aydın (a) and Yozgat (b) floor plans of reference blocks.

1. *The Brink of Stress vs. Optimal Comfort:* The simulation highlights a critical divergence in thermal resilience. In Yozgat, the building maintains 'Optimal Comfort,' with equivalent temperatures varying safely between 23.05°C and 24.11°C, benefiting from the milder summer climate. Conversely, Aydın operates on the 'Brink of Stress.' The average temperatures range from 24.95°C to 25.97°C, hovering dangerously close to the 26°C upper limit of the UTCI "no thermal stress" zone. This indicates that in the hot-climate context, the

building envelope barely manages to resist the ambient heat load, leaving almost no buffer against potential heatwaves.

2. *Spatial Shift:* A distinct spatial inversion is observed in both locations compared to the annual trends. Contrary to the annual dominance of the South façade, the summer heat gain is concentrated heavily in the Eastern zones. This is attributed to solar geometry: the low-angle morning sun penetrates deep into these rooms, bypassing the horizontal balconies which are ineffective against lateral angles. In contrast, the Southern zones—typically the warmest—appear relatively cooler (Blue tones). This reversal demonstrates the effectiveness of the balconies acting as overhangs against the high solar altitude of summer, successfully shading the south façade while the east remains exposed.

The summer analysis exposes a critical 'Architectural Blind Spot' in the standardized design. While the balcony overhangs successfully protect the South façade from the high noon sun (proving effective shading geometry), they fail completely to shield the East façade from the low-angle morning sun.

In Yozgat, this exposure is manageable; however, in Aydın, the East façade emerges as a 'Thermal Weak Point' that pushes indoor conditions to the very edge of the stress threshold. This confirms that relying solely on horizontal shading (balconies) is insufficient for the Mediterranean climate. To prevent overheating in the critical eastern zones, the typology requires the integration of vertical shading devices or adjustable louvers capable of blocking low-angle solar ingress.

The Winter UTCI analysis (December–February) serves as the definitive test for the building envelope's insulation capabilities and its ability to utilize passive solar energy. The comparative assessment of Aydın and Yozgat (Figure 23) reveals how the same building typology responds to mild versus harsh winter conditions.

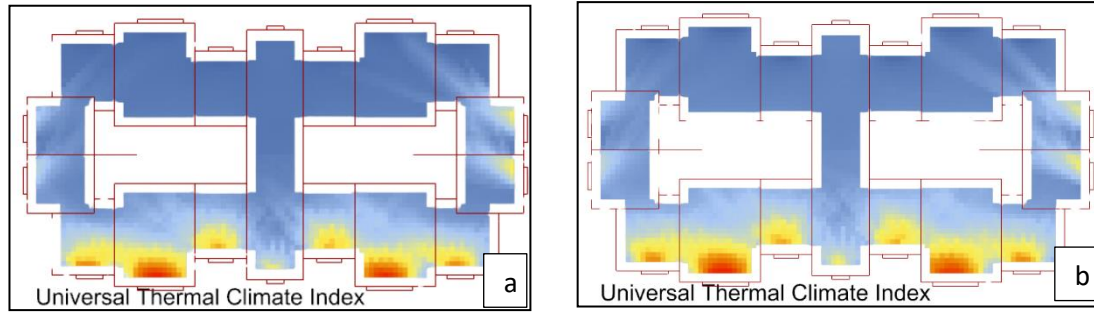


Figure 23. Seasonal (winter) Universal Thermal Climate Index (UTCI) distribution analysis of the Aydın (a) and Yozgat (b) floor plans of reference blocks.

1. *Quantitative Resilience:* While both simulations successfully avoid "cold stress" ($<9^{\circ}\text{C}$), the quality of the indoor environment differs. In Aydın, the performance is exceptionally stable; average equivalent temperatures range between 20.24°C and 21.40°C , remaining consistently above the ideal comfort threshold due to the envelope's ability to easily retain heat. Conversely, Yozgat demonstrates resilience against severe external conditions. Temperatures settle between 19.27°C and 20.44°C . Although the northern zones dip slightly below the ideal 20°C mark, the envelope effectively maintains a habitable baseline, acting as a robust barrier preventing the deep thermal drops expected in such a cold region.
2. *The Directional Divide:* A critical dichotomy governs the winter performance. The South Façade acts as the 'Thermal Anchor' for both plans, where low-altitude winter sun penetrates the glazing to maximize passive heating. In Yozgat, this is not just a benefit but a necessity, pushing southern room temperatures up to 20.44°C . In contrast, the Northern Zones reveal the true climatic pressure. While Aydın's northern rooms maintain comfortable levels ($>20^{\circ}\text{C}$) without direct sun, Yozgat's northern zones drop to $\sim 19.3^{\circ}\text{C}$ (Dark Blue). This confirms that in the absence of solar gain, the continental case relies entirely on the material insulation properties to resist conductive heat loss.

The winter analysis validates the envelope's insulation standards but exposes a critical 'Passive Dependency' in the heating-dominated climate. In Aydın, comfort is 'Omni-Directional'; the envelope alone is sufficient to maintain ideal conditions regardless of orientation. In Yozgat, however, comfort becomes 'Directional.' The building relies heavily on the South-facing solar gains to balance the thermal equation. This implies

that while the standardized block is robust enough to prevent cold stress in Yozgat, its ability to provide 'ideal comfort' is strictly tied to solar orientation, leaving the Northern zones functioning at a lower thermal tier compared to the rest of the house.

6.4. Comparative Evaluation of Simulation Results

This section serves as a proof-of-concept for the proposed computational workflow, synthesizing the simulation results to validate its diagnostic capabilities. By applying the methodology to the reference buildings in Aydın (1st Zone) and Yozgat (4th Zone)—selected as the study's strategic 'Pivot Cities'—the analysis demonstrates the workflow's capacity to detect critical performance divergences from identical baselines. Although the test cases share identical plan typologies, orientations, and fenestration ratios, the workflow successfully quantified their fundamentally opposite responses to environmental forces. Consequently, this comparison functions as the primary verification of the research method, proving its effectiveness in exposing the 'Performance Gap' inherent in standardized design and establishing a robust, data-driven foundation for the subsequent optimization phase.

The Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI) analyses revealed a critical paradox regarding solar access. In the Aydın case (Hot-Dry), the high Daylight Autonomy levels observed, particularly on the eastern and southern façades, represent a liability rather than an asset during the cooling season. As evidenced in the Summer UDI analysis, the perimeter zones are dominated by "UDI-exceeded" values (>2000 lux). This confirms that the standard window dimensions, while maximizing light, admit excessive direct solar radiation, leading to potential glare and contributing to the overheating risks identified in the thermal analysis. Conversely, in the Yozgat case (Cold-Continental), the high saturation of daylight observed on the southern façade during winter is highly beneficial. The DA and UDI results indicate that the south-facing habitable rooms receive "useful" daylight (100–2000 lux) deep into the floor plan. In this heating-dominated climate, this solar penetration acts as a passive heat source, compensating for conductive heat losses. Therefore, while the high-intensity zones in the simulation maps appear identical in both cities, their architectural implication is contradictory: Aydın requires solar control to mitigate this gain, whereas Yozgat relies on it for passive survivability.

The comparative analysis of the Universal Thermal Climate Index (UTCI) further highlights the seasonal shifts in occupant comfort. The most significant disparity occurs in the summer period. The Yozgat building performs exceptionally well, with average UTCI values ($\sim 23\text{-}24^{\circ}\text{C}$) remaining safely within the comfort zone due to the cooler continental air mass. In contrast, the Aydın building operates at the upper threshold of thermal comfort ($\sim 25\text{-}26^{\circ}\text{C}$). The simulation data explicitly shows that the eastern zones in Aydın are vulnerable to morning overheating, pushing the indoor environment toward "moderate heat stress" limits. The winter analyses reverse this dynamic. The Aydın building maintains a naturally comfortable baseline ($>20^{\circ}\text{C}$) with minimal fluctuation. However, the Yozgat building exhibits a sharp spatial divide: while south-facing rooms maintain comfort through the aforementioned passive solar gains, the north-facing zones experience a noticeable drop in temperature ($\sim 19.3^{\circ}\text{C}$), creating a thermal imbalance within the unit.

In conclusion, the simulation results prove that a "one-size-fits-all" mass housing approach fails to optimize energy efficiency in conflicting climates. The standard 2+1 plan typology performs reasonably well in Yozgat's summer but requires better insulation or zoning for its winter north façade. Conversely, the exact same design in Aydın is successful in winter but critically lacks passive cooling and shading strategies for the summer. This comparative evaluation underscores that "passive design" is not a static product but a climate-specific adaptation process.

CHAPTER 7: DISCUSSION

This chapter synthesizes the qualitative findings derived from occupant surveys with the quantitative outputs of the simulation analyses, using the proposed mixed-method workflow as an interpretive framework. Rather than treating either dataset as independently conclusive, the discussion focuses on how their intersection reveals patterns of convergence and divergence between predicted and perceived performance.

The objective of this integrated evaluation is not to verify simulation accuracy through user feedback, nor to treat occupant perception as a direct measure of energy performance. Instead, the discussion illustrates how combining these data streams enables a more comprehensive understanding of inconsistencies that may arise from standardized design decisions, climatic mismatch, and user adaptation strategies.

7.1. Integrated Evaluation of User Experience and Simulation Results

This section examines the applicability of the proposed mixed-method workflow in linking objective data obtained from building performance simulations (Chapter 6) with subjective feedback gathered through user surveys (Chapter 5). The aim is to explore how the framework reveals areas of alignment and divergence between theoretical predictions and real-world occupant experience. By applying this workflow to the pilot case studies, the performance of standardized TOKI typologies is analyzed under four main headings to reflect on the diagnostic potential of the methodology.

7.1.1. Thermal Comfort

The application of the proposed evaluation framework to the pilot cases reveals a critical convergence between the computational simulation and the user feedback components. This alignment serves as the primary validation of the workflow, proving its robustness not only in calculating theoretical values but in accurately predicting real-world occupant distress and adaptive behaviors.

The workflow successfully translated the theoretical "heat stress" into tangible user dissatisfaction. The simulation diagnosed that the building operates at the upper threshold of the comfort zone (25–26°C UTCI) during summer in Aydın. This quantitative warning was strongly corroborated by the qualitative survey, where 41.7% of residents reported a "high need" for mechanical cooling. In the heating-dominated context (Yozgat), the workflow moved beyond general averages to identify specific "spatial divides."

Simulations highlighted the North-facing zones as thermally vulnerable (~19.3°C), a finding that aligned directly with survey data where 34.8% of respondents reported frequent heating needs. Crucially, the correlation between the simulated low surface temperatures and the users' reported reliance on personal measures (e.g., heavy carpets) provides "behavioral verification" of the simulation results.

The high dissatisfaction rate in living rooms is structurally justified by the plan typology. Since two of the four units on each floor position their living areas on the critical North façade, the simulation's finding of "Northern Deficiency" directly explains the complaints from half of the user base. This confirms that the standardized plan creates a "Thermal Inequality" among neighbors on the same floor. Interestingly, dissatisfaction was also noted in South-facing units. This discrepancy highlights the role of "Occupancy Duration."

Since the living room is the primary zone of sedentary activity, users are physiologically more sensitive to thermal variations there compared to bedrooms, which are used primarily for sleeping under thermal covers. Thus, even minor simulated deviations in the living room translate into major user complaints. Similarly, the variation between users identifying the "Kitchen" versus the "Living Room" as the most problematic space—despite both sharing the same façade orientation and thermal physics—can be attributed to demographic usage patterns. Users who spend prolonged periods in the kitchen (e.g., homemakers) identify it as the primary stress zone. This validates that the "perceived comfort" is a function of time spent in the zone, further emphasizing the need for the workflow to prioritize high-occupancy areas.

Ultimately, the integrated evaluation proves that the proposed workflow does not just output temperature data; it successfully mirrors the complex reality of user experience. By accurately predicting the dissatisfaction in North-facing living rooms and

correlating high-occupancy zones with high-sensitivity feedback, the methodology confirms that the 'Performance Gap' is not an abstract concept, but a tangible design failure affecting the daily lives of residents.

7.1.2. Visual Comfort & Daylight Perception

The integrated analysis highlights the workflow's capacity to decode the disconnect between software predictions and daily life practices, quantifying the phenomenon often referred to as the "Solar Paradox."

A critical contradiction emerged in the Aydın pilot case. While users verbally confirmed that the city is "always sunny" and the building receives abundant sunlight, they simultaneously reported a high dependency on artificial lighting during the day. This validates the simulation's "Glare Risk" (>2000 lux) finding. The abundance of light is physically present but functionally unusable due to visual discomfort.

The survey revealed that 83.3% of residents use thick curtains to block this harsh sunlight. This creates a "Black Box Effect": users are forced to block the natural light to escape the heat/glare, creating a self-inflicted darkness that necessitates artificial lighting at noon. This confirms the workflow's critique: without architectural shading, more glass does not mean more daylight; it often means more energy consumption.

The workflow identified that the East and West façades physically receive less light due to the "contextual shading" from neighboring blocks. However, user complaints remained heavily concentrated on the Living Room and Kitchen, regardless of their orientation. This discrepancy highlights that "Perceived Darkness" is not just about Lux levels, but about "Visual Task Intensity." A bedroom (East/West) remaining in shadow is tolerated because it is a low-activity zone used mostly for sleeping. Conversely, the Kitchen and Living Room are high-activity zones requiring visual acuity for cooking and socializing. Therefore, users are psychologically more sensitive to insufficient light in these spaces. Even a minor drop in daylight levels in the kitchen triggers a stronger negative reaction than a major shadow on the bedroom façade. This proves that the standardized design fails to prioritize daylight access for the "working zones" of the house, treating all rooms as identical boxes.

The analysis exposes a flaw in the user control mechanisms. The standard typology offers only a binary choice: fully exposed glazing (Glare) or fully closed thick curtains (Darkness). There is no intermediate architectural filter (e.g., light shelves or louvers). This lack of control explains why 27.8% of users indicate a high dependency on artificial lighting even in theoretically "well-lit" zones.

The integration of user feedback validates that 'Daylight Performance' is not merely a radiometric metric but a function of occupancy and task. The workflow confirms that the standardized building envelope fails on two fronts: it oversaturates the perimeter with unusable glare (forcing curtains closed) and fails to deliver quality light to high-task areas like the kitchen. This forces users into a cycle of 'protective adaptation,' where they paradoxically rely on artificial lighting to fix the failures of natural lighting design.

7.1.3. Indoor Air Quality & Ventilation

While the simulation module focused on thermal parameters, the mixed-method structure of the workflow allowed for the indirect assessment of ventilation issues that a single-method study might miss. In both pilot settlements, satisfaction with indoor air quality remained "moderate" (score 3/5). Although the simulation did not model air quality directly, the integrated evaluation linked this dissatisfaction to the thermal constraints identified in the climate analysis.

In Aydın (summer) and Yozgat (winter), the simulations confirm extreme outdoor temperatures. Consequently, the potential for natural ventilation is effectively blocked by the thermal penalty; users cannot open windows without destroying their indoor thermal balance (letting in extreme heat or freezing cold).

Despite a remarkably low internal pollution load (87% of households are non-smoking), air quality satisfaction did not improve. This scientifically confirms that the "moderate" air quality is not due to user habits (smoke/cooking) but is a systemic failure. The building envelope compels users to hermetically seal their living spaces to preserve heat during the harsh winter. The lack of air exchange is a direct byproduct of the heating strategy.

Crucially, the workflow exposes a critical flaw in the standardized ventilation strategy. The design assumes 'Natural Ventilation' (opening windows) as the primary fresh air source. However, the simulation proves that for significant portions of the year in both 1st and 4th Climate Zones, opening windows is thermally prohibitive. By forcing users to choose between stale warm air and fresh freezing/scorching air, the typology fails to provide a healthy indoor environment, highlighting the necessity for passive vents or heat-recovery ventilation systems in extreme climates.

7.1.4. Material Performance & Building Envelope

The pilot application revealed a critical divergence between theoretical assumptions and field observations, underscoring the necessity of including a qualitative loop in the evaluation workflow.

While standard energy simulations focused on U-values (thermal transmission), they operated under the assumption of a dry, intact envelope. The survey component shattered this assumption, revealing that 73.5% of residents in Aydın observed mold or dampness. It suggests that while the walls may theoretically resist heat, the junction points (thermal bridges) fail to manage moisture in the humid 1st Climate Zone. The workflow proves that a "thermally compliant" building can still be biologically unsafe, highlighting a pathology that pure thermal modeling misses without coupled moisture analysis.

In Yozgat, a staggering 78.3% of users reported cracks and leaks in the building envelope. This finding highlights a critical limitation of static energy modeling, which typically assumes a fixed air-tightness rate (infiltration). The user feedback reveals that freeze-thaw cycles in the 4th Climate Zone have caused physical deterioration, likely increasing actual infiltration rates far beyond theoretical predictions. This means the building is losing significantly more heat through not modeled leaks than the simulation estimates.

This section validates the workflow as a 'Reality Calibration' tool. Standard simulations predict the performance of a 'perfect' building that exists only in digital space. However, the user feedback exposes the 'Performance Decay' of the actual physical asset. By identifying widespread mold (Aydın) and structural cracks

(Yozgat), the workflow confirms that relying solely on U-values is deceptive; true performance evaluation must account for the physical integrity and degradation of the material envelope over time.

Lastly, Table 6 offers a comparative evaluation that illustrates how simulation outputs and occupant feedback both converge and diverge across the two pilot cases, reinforcing the value of the proposed mixed-method workflow. By juxtaposing predicted performance outcomes—derived from climate-based environmental simulations—with user-reported comfort perceptions and adaptation strategies in Aydın and Yozgat, the framework demonstrates its ability to reveal layered performance dynamics. In instances where the simulations projected potential issues—such as excessive overheating in Aydın or insufficient passive heat retention in Yozgat—users similarly reported thermal discomfort and undertook compensatory actions. This alignment suggests that the workflow can effectively translate theoretical performance assumptions into context-specific, lived experience insights. Furthermore, Table 6 highlights regionally distinct architectural limitations—such as the absence of fixed shading in Aydın or inadequate solar orientation in Yozgat—that would likely be overlooked through single-method evaluations. In sum, this synthesis underscores how the integration of quantitative simulations and qualitative survey data enables a more context-aware, user-informed assessment of passive design performance.

Table 6. Comparison of Simulation Results and Survey Feedback

Performance Aspect		Aydın	Yozgat
Summer Overheating	Simulation Prediction	Extreme solar exposure, overheating risk (~25–26 °C UTCI), unshaded design acts as “heat trap”.	No overheating predicted; indoor summer conditions within comfort range (~23–24 °C).
	User Perception (Survey Feedback)	Excessive heat reported in living rooms; 41.7% of users require cooling systems.	Most users report low need for cooling; summer comfort is manageable.
	User Response (Adaptive Strategies)	73.5% use permanent curtain closure, some use AC or fans.	65.2% employ natural ventilation, minimal mechanical cooling usage.

Table 6 (continued). Comparison of Simulation Results and Survey Feedback

Performance Aspect		Aydın	Yozgat
Winter Cold & Passive Solar Heating	Simulation Prediction	Mild winter, indoor temps ~20–21 °C, no cold stress predicted.	Just avoids cold stress (~19–20 °C); strong reliance on south-facing sun, north rooms underheated.
	User Perception (Survey Feedback)	Mediocre comfort reported (~3/5); poor insulation noted, heat loss through envelope.	High mechanical heating reliance; large windows cause heat loss, living room noted as coldest by 47.8%.
	User Response (Adaptive Strategies)	80.6% use DIY insulation (e.g. window sealing), heaters, blankets.	95.7% use carpets, drapes, extra window layers, reposition furniture to avoid cold spots.
Daylight & Visual Comfort	Simulation Prediction	Abundant sunlight but uneven distribution; south rooms overlit, north rooms underlit; central zones at 0% daylight.	Balanced daylight, supports passive heating; some glare, but distribution better than Aydın.
	User Perception (Survey Feedback)	Mixed views; 41.7% satisfied, 27.8% still rely on lights; glare forces curtain use.	Mostly satisfied (4/5); moderate need for artificial lighting (3/5); deep rooms occasionally dim.
	User Perception (Survey Feedback)	83.3% adjust curtains/blinds constantly; use heavy curtains, films, rearranged furniture.	78.3% use sheer curtains, move furniture to optimize daylight; occasional task lighting added.

7.2. Evaluation of Climate-Responsive Design Strategies in Mass Housing

The application of the proposed evaluation workflow to the pilot case studies enables a contextual analysis of how standardized mass housing typologies respond to distinct climatic conditions. As demonstrated in the representative examples, the workflow confirmed that identical floor plans, spatial configurations, and standard window dimensions were implemented in both the hot-arid climate of Aydın and the cold-continental setting of Yozgat—despite their markedly different environmental demands.

The workflow revealed a design rigidity that limits climatic responsiveness. For instance, in Yozgat, the Window-to-Wall Ratio (WWR) was found to be slightly higher than in Aydın. While increased glazing can enhance passive solar gain on south-facing façades in colder regions, applying the same configuration uniformly to north-facing walls results in excessive heat loss. This condition illustrates what the framework identifies as directional insensitivity—a failure to calibrate façade strategies based on solar orientation and thermal dynamics.

In Aydın, the evaluation highlighted the absence of integrated shading elements. Although the standardized window dimensions comply with national codes, they lack protective features against excessive solar gain. The survey results corroborated this shortcoming: residents reported substantial summer discomfort and engaged in retrospective adaptations such as closing balconies with glass or installing heavy curtains. These user-led modifications point to a reactive form of thermal regulation, compensating for the lack of passive solar control in the original design.

Crucially, both cases underscore a broader issue: the current reliance on prescriptive construction standards (e.g., TS 825) rather than performance-oriented design thinking. While insulation levels meet regulatory requirements, the simulations and user feedback demonstrate that thermal performance is strongly influenced by spatial geometry, solar orientation, and envelope articulation. In this regard, the study illustrates that material-based solutions cannot substitute for design responsiveness.

Instead of diagnosing a fixed “performance gap,” the framework captures the interaction between design assumptions and real-world responses. It suggests that the prevailing model of 'Prototype Application'—which applies identical plans nationwide—fails to deliver effective passive performance under variable climatic conditions. The results point toward the necessity of a Typological Adaptation approach, wherein massing, façade design, and passive elements are treated as flexible variables, optimized according to regional context and user needs. Without such an adaptive framework, the limitations observed in these pilot cases are likely to persist across future housing stock.

CHAPTER 8: CONCLUSION

8.1. Summary of Findings

This study was initiated to develop and apply a mixed-method evaluation workflow for assessing passive design strategies in standardized mass housing in Türkiye. Using TOKİ's uniform housing typologies as a controlled base, the main objective was to explore how predicted performance metrics align—or diverge—from user-perceived indoor environmental conditions across differing climates. To test the applicability of the proposed framework, two pilot settlements were selected to represent distinct climatic contexts: Aydın (Hot–Arid) and Yozgat (Cold–Continental). By integrating quantitative simulation outputs (DA, UDI, UTCI) with qualitative data from post-occupancy surveys, the study enabled a multidimensional assessment of how standardized architectural designs perform under varied environmental conditions, not through energy outputs but through the interaction between modeled assumptions and lived user experiences.

In Aydın (Cooling-Dominated), the standard envelope fails to mitigate excessive solar heat gain. Simulations confirmed that the building operates at the upper limits of thermal comfort, with Eastern zones particularly prone to overheating. This was corroborated by survey results, where a majority of residents reported a high dependency on mechanical cooling. In Yozgat (Heating-Dominated), the same typology exhibits a "Thermal Imbalance." While the Southern façade benefits from passive solar heating, the Northern zones suffer from significant heat loss. Survey data confirmed this "spatial divide," with residents reporting frequent heating needs despite the high insulation standards.

High daylight availability, typically a positive attribute, manifests as a liability in Aydın due to the absence of shading, leading to glare and overheating risks. Conversely, in Yozgat, this solar access acts as a vital passive asset for winter heating. The study confirms that standardized Window-to-Wall Ratios (WWR) are not optimized for these conflicting functions; they are too large/unprotected for Aydın's summers, yet lack the directional sensitivity required for Yozgat's winters.

A critical insight derived from the qualitative workflow is the resilience of the occupants. In the absence of built-in passive strategies (such as structural shading), residents have developed "Compensatory Adaptive Behaviors." The widespread use of heavy curtains, glass balcony enclosures, and window taping serves as empirical validation that users are actively intervening to correct the architectural deficiencies of the standardized design.

In summary, the pilot applications confirm that the current "one-size-fits-all" production model, while structurally efficient, falls short in delivering energy-efficient living environments. The study provides evidence that true sustainability in mass housing cannot be achieved through material specifications (U-values) alone. It requires a fundamental shift towards "Typological Adaptation," where building form, orientation, and façade design are intrinsically molded by the local climate.

In conclusion, this thesis suggests that a mixed-method evaluation workflow can offer a more nuanced understanding of passive design performance in standardized mass housing than simulation-based analysis alone. By revealing how climatic conditions, design uniformity, and occupant adaptation intersect, the proposed approach introduces an analytical structure that may be transferable to future climate-responsive housing research and design evaluation processes. Its value lies not in generalizing performance outcomes, but in structuring how passive design is critically examined through the integration of predictive and experiential data.

8.2. Limitations of Study

The findings of this study should be interpreted in light of several limitations inherent to its scope and methodology. First, the evaluation workflow was applied to two pilot case studies, which restricts the ability to generalize the observed performance outcomes to the entirety of TOKİ housing stock or to all climatic regions of Türkiye.

Second, the qualitative component relies on self-reported occupant perceptions, which, while essential for understanding lived experience and adaptive behavior, cannot be equated with measured operational performance. The absence of long-term monitored indoor environmental data and energy consumption records limits the capacity to quantify the full extent of the performance gap.

These limitations, however, do not undermine the methodological contribution of the study. On the contrary, they clarify the intended role of the proposed workflow as a diagnostic and exploratory evaluation tool, suitable for extension and refinement through future studies incorporating larger samples, additional climatic contexts, and empirical performance measurements.

8.3. Potential Directions for Future Research

This study proposed and applied a mixed-method evaluation workflow for assessing the passive design performance of mass housing. Informed by the pilot case studies and the identified limitations, several key directions are suggested to broaden the scope and adaptability of the proposed analytical framework.

This research utilized two pilot regions representing Türkiye's extreme climatic zones (hot-dry and cold-continental) to test the sensitivity of the evaluation method. Future studies can apply this transferable workflow to cover all six climate zones defined in the revised TS 825 standard. By replicating the proposed methodology across a broader geographical context, a comprehensive "Passive Design Map of Türkiye" can be developed, validating the workflow's adaptability to transitional and temperate climates.

To ensure comparative consistency within the pilot validation phase, this study standardized the analysis on a single architectural plan scheme (2+1 apartment units). Future research can test the robustness of the evaluation framework by incorporating a wider variety of residential typologies, including 3+1 and 1+1 unit types, as well as different building forms (e.g., L-shaped or U-shaped blocks). Investigating these variations will provide a more holistic understanding of how the proposed assessment model accounts for the influence of building form and spatial organization on perceived environmental quality.

While this study focused on evaluating the interaction between simulated performance indicators and user-perceived indoor conditions, future research can expand the workflow to simulate potential retrofit strategies. Building on the comparative insights gained from the current methodology, new studies can assess the impact of targeted passive interventions—such as dynamic shading devices, improved glazing systems,

or upgraded insulation—on user comfort and performance perception across varied climates.

User comfort in this study was assessed through subjective surveys as part of the qualitative validation component. To further refine the accuracy of the evaluation workflow, future research can integrate longitudinal physical monitoring using IoT-based sensors to record real-time data on temperature, humidity, and CO₂ levels. Collecting long-term field data will allow for the calibration of simulation models within the workflow and support a more comprehensive interpretation of environmental performance aligned with user perception.



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APPENDICES

APPENDIX A – Revised Climate Zoning in Türkiye (TS 825 – 2025 Update)

In response to growing concerns over climate resilience, energy efficiency, and the need for region-specific thermal regulations, the Turkish Standards Institute revised TS 825 in late 2024. The updated regulation was officially enacted under Communiqué No: MHGM-2025/1, published in the Official Gazette on 20 February 2025, and entered into force on 1 April 2025 (Resmî Gazete, 2025).

One of the most notable updates in TS 825 is the expansion of climate zoning from four to six regions, aiming to more accurately reflect Türkiye’s climatic diversity. Unlike the previous classification system, which was based solely on annual heating degree-days, the revised zoning incorporates additional parameters such as cooling demand, solar radiation, and humidity (İZODER, 2024). This shift enhances the geographic precision of thermal regulations and supports more effective passive design strategies. The new climate zones are categorized as follows:

Heating Degree-Day Region 1 – Very Hot (red)

Heating Degree-Day Region 2 – Hot (orange)

Heating Degree-Day Region 3 – Mild (beige)

Heating Degree-Day Region 4 – Cold (green)

Heating Degree-Day Region 5 – Very Cold (blue)

Heating Degree-Day Region 6 – Extremely Cold (dark blue)



Figure 24. Climate regions according to the Turkish building code TS825 (2024)

The revised standard also introduces more stringent U-value limits for thermal transmittance across building envelope components. For example, in Climate Zone 3 (which includes Istanbul), the maximum allowable U-value for windows is reduced to 1.8 W/m²·K, with even stricter values proposed for high-glazing buildings (İZODER, 2024). Wall, roof, and floor components are similarly updated to support better energy performance and thermal comfort year-round.

Table 7. U-value requirements according to TS 825 (2024)

Climate Zone (TS 825 - 2024)	Wall U (W/ m ² K)	Roof U (W/ m ² K)	Floor U (W/ m ² K)	Window U (W/ m ² K)
1 st Zone	0.45	0.35	0.40	1.8
2 nd Zone	0.40	0.30	0.35	1.8
3 rd Zone	0.40	0.30	0.35	1.8
4 th Zone	0.35	0.25	0.30	1.8
5 th Zone	0.25	0.20	0.25	1.8
6 th Zone	0.25	0.20	0.25	1.8

Crucially, TS 825:2024 encourages performance-based assessment, a shift from its earlier prescriptive orientation. While baseline U-values remain a compliance requirement, the revised framework supports dynamic simulation approaches—factoring in solar gains, natural ventilation, and internal heat loads—in line with international methodologies such as EN ISO 52000 and EN 13790 (Schimschar et al., 2016). This evolution brings TS 825 into closer alignment with the Energy Performance of Buildings Directive (EPBD) adopted by the European Union.

From a policy and implementation standpoint, the updated TS 825 represents a major leap forward. For public housing authorities like TOKİ, which previously designed units under the older zoning system, the 2024 revision provides a robust basis for

applying passive energy principles in new construction, while also informing retrofit strategies for existing housing stock.



APPENDIX B - Distribution of TOKİ Projects by Province

CITY	NUMBER OF PROJECTS	CITY	NUMBER OF PROJECTS	CITY	NUMBER OF PROJECTS
Adana	105	Erzurum	81	Muş	17
Adıyaman	71	Eskişehir	49	Nevşehir	45
Afyon	83	Gaziantep	106	Niğde	54
Ağrı	40	Giresun	37	Ordu	36
Aksaray	39	Gümüşhane	26	Osmaniye	48
Amasya	33	Hakkari	25	Rize	46
Ankara	330	Hatay	244	Sakarya	44
Antalya	45	Iğdır	12	Samsun	49
Ardahan	18	Isparta	40	Siirt	18
Artvin	15	Mersin	48	Sinop	20
Aydın	31	İstanbul	354	Sivas	72
Balıkesir	67	İzmir	86	Şanlıurfa	98
Bartın	13	Kahramanmaraş	119	Şırnak	36
Batman	46	Karabük	38	Tekirdağ	39
Bayburt	18	Karaman	29	Tokat	47
Bilecik	25	Kars	29	Trabzon	102
Bingöl	51	Kastamonu	36	Tunceli	34
Bitlis	36	Kayseri	71	Uşak	24
Bolu	47	Kırıkkale	37	Van	110
Burdur	40	Kırklareli	23	Yalova	15
Bursa	100	Kırşehir	38	Yozgat	65
Çanakkale	35	Kilis	13	Zonguldak	37
Çankırı	48	Kocaeli	73		
Çorum	45	Konya	165		
Denizli	67	Kütahya	81		
Diyarbakır	101	Malatya	157		
Düzce	39	Manisa	69		
Edirne	38	Mardin	38		
Elazığ	72	Muğla	36		

APPENDIX C – Visual Documentation of Selected TOKI Projects



Figure 25. TOKİ Housing Complex in Aydın (Source: Aydın, TOKI)

Aerial view of the constructed housing blocks in the Aydın project site. The image illustrates the compact settlement pattern and the spacing between blocks. The distinctive blue and white façade coloration and the terracotta roof tiles represent the standardized aesthetic applied in this Mediterranean climate zone.



Figure 26. TOKİ Housing Complex in Aydın (Source: Aydın, TOKI)

The color-coded schema distinguishes the 3+1 blocks (Yellow) from the 2+1 blocks (Blue) to illustrate the typological distribution.



Figure 27. TOKİ Housing Complex in Aydın (Source: Aydın, TOKI)

Exterior perspective views of the reference blocks in Aydın. These visuals highlight the fenestration ratios (Window-to-Wall Ratio) and the placement of balconies. The balconies act as the primary fixed shading elements in the simulation model, determining the extent of solar protection provided to the living spaces during the high-radiation summer months.



Figure 28. TOKİ Housing Complex in Yozgat (Source: Yozgat, TOKI)

Site overview of the Yozgat settlement, characterized by strict typological homogeneity. All residential blocks share identical massing and façade articulation, creating a repetitive architectural language.



Figure 29. TOKİ Housing Complex in Yozgat (Source: Yozgat, TOKI)

The site layout is organized around a central social core, featuring integrated green zones and seating areas designed for communal use.

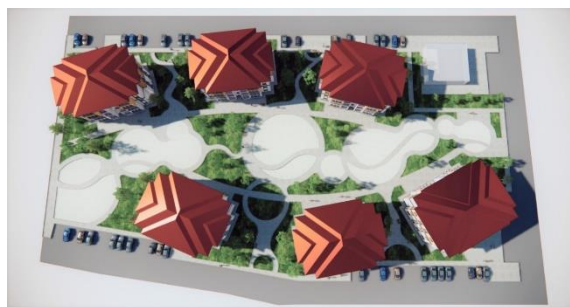


Figure 30. The Site Plan of Yozgat Toki Housing Complex (Source: Yozgat, TOKI)

Top-down site plan configuration of the Yozgat settlement. This layout forms the basis for the "contextual shading" analysis in the energy simulations. The distance and orientation of the neighboring blocks determine the "shadow masks" cast on the reference building, influencing solar access and passive heating potential during winter.

APPENDIX D – Construction Details of Building Envelope Elements

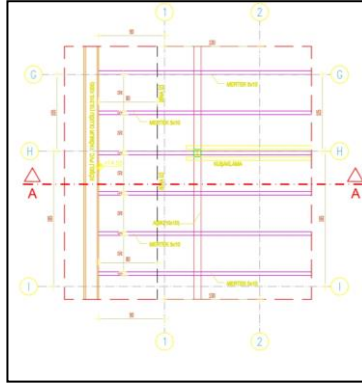


Figure 31. Detailed Roof Plan Drawing of Aydın TOKİ Housing Complex. (Data Source: TOKİ)

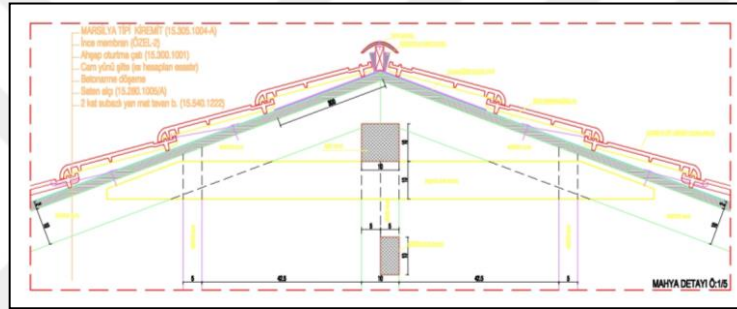


Figure 32. Detailed Roof Section Drawing of Aydın TOKİ Housing Complex. (Data Source: TOKİ)

Technical roof plan illustrating the drainage system and tiling layout. The drawing specifies the use of "Marseille type" clay tiles and the gutter arrangement. This geometry defines the roof's solar exposure surface area in the simulation environment.

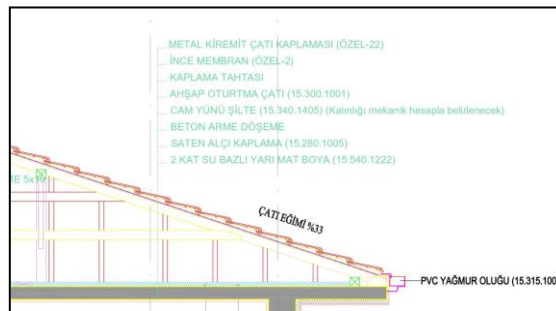


Figure 33. Detailed Roof Section Drawing of Yozgat TOKİ Housing Complex. (Data Source: TOKİ)

Comparative vertical sections of the roof assembly. The details identify the specific material layers, including the "glass wool quilt" (cam yünü şilte) insulation and the timber truss system. These material specifications were used to calculate the Roof U-value input for the energy model, verifying whether the thermal resistance is adjusted for the specific climate zone.

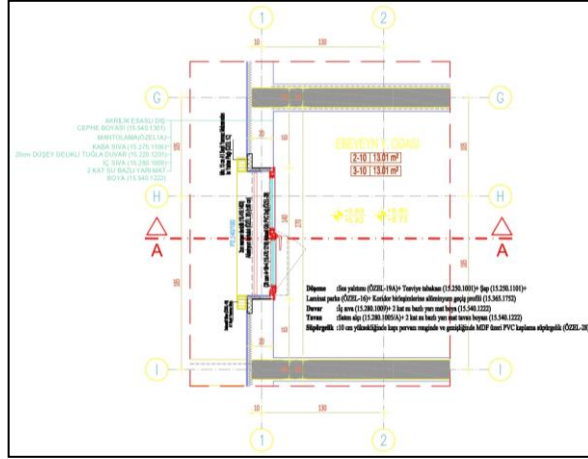


Figure 34. Detailed Wall Plan Drawing of Aydın TOKİ Housing Complex. (Data Source: TOKİ)

Plan section focusing on the external wall composition. The drawing details the "20cm brick" (tuğla) core and the external thermal insulation composite system (sheathing/mantolama). This detail is the primary source for defining the thermal mass and conductivity of the opaque vertical envelope in the simulation.

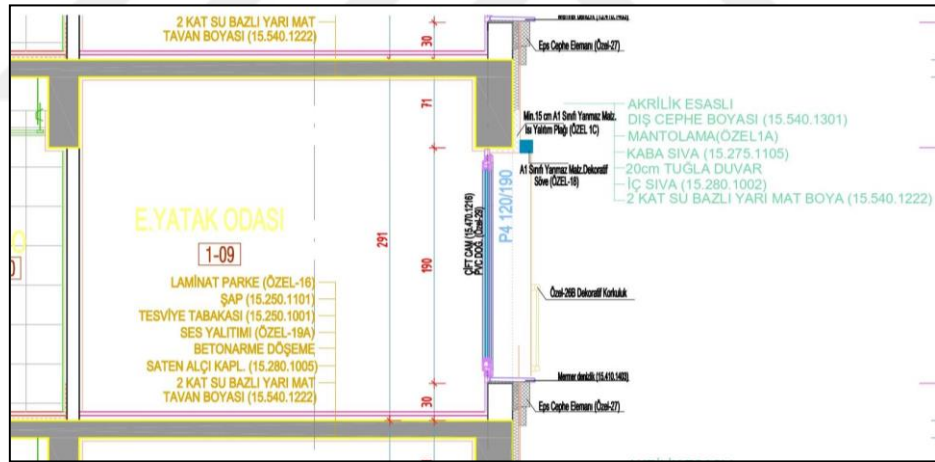


Figure 35. Detailed Wall Section Drawing of Yozgat TOKİ Housing Complex. (Data Source: TOKİ)

Vertical wall section showing the junction between the floor slab, the external wall, and the window sill. The detail illustrates the continuity of the insulation layer (thermal bridge prevention) and the material build-up used to determine the Wall U-value for the heating-dominated Yozgat climate.

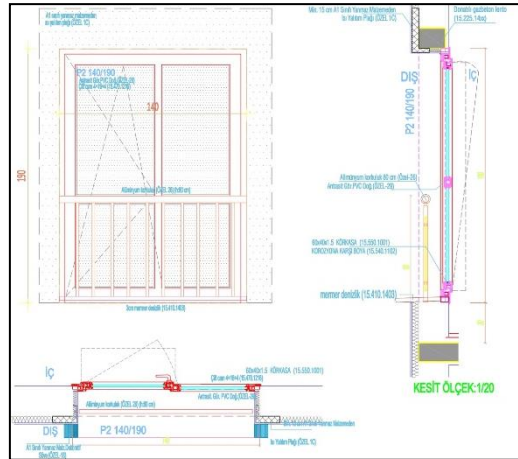


Figure 36. Detailed Window Drawing of Aydın TOKİ Housing Complex. (Data Source: TOKİ)

Technical elevation and section details of the fenestration units. The drawings specify the use of PVC frames and double-glazing units (4+16+4 mm). These specifications define the Window U-value and Solar Heat Gain Coefficient (SHGC) used in the simulations, which are critical for analyzing heat loss in Yozgat and heat gain in Aydın.

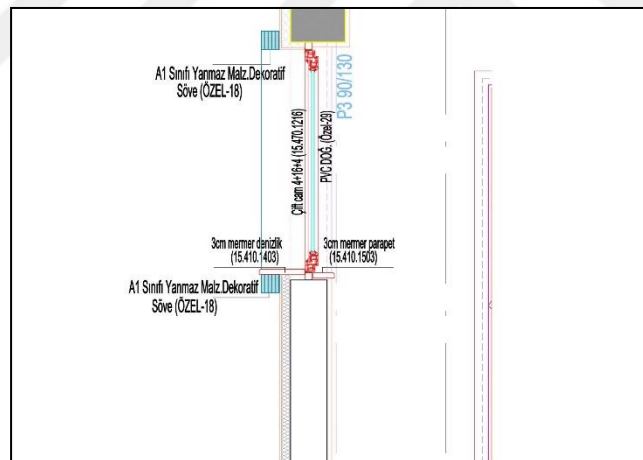


Figure 37. Detailed Window Section Drawing of Yozgat TOKİ Housing Complex.
(Data Source: TOKİ)

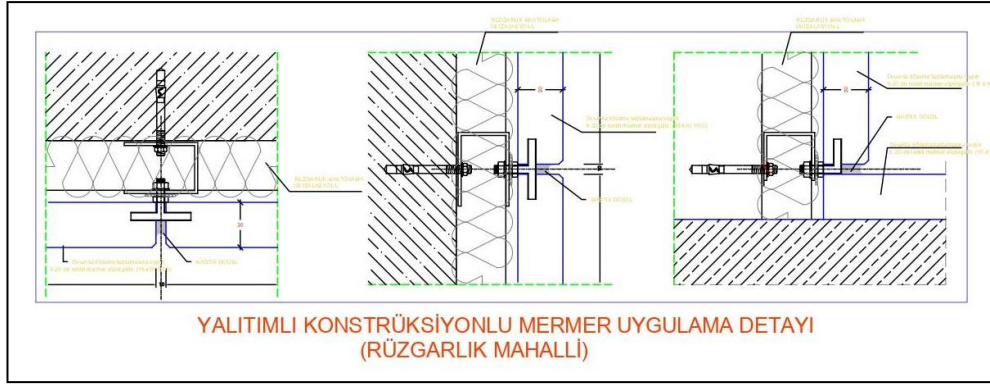


Figure 38. Detailed Insulation Drawing of Aydın TOKİ Housing Complex. (Data Source: TOKİ)

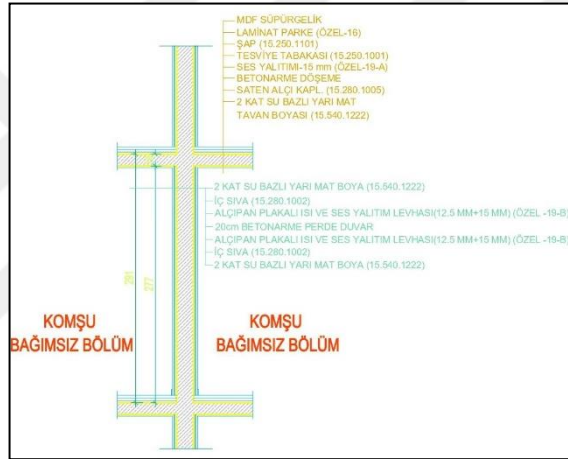


Figure 39. Detailed Insulation Drawing of Yozgat TOKİ Housing Complex. (Data Source: TOKİ)

Partition wall details illustrating the sound and heat insulation strategies between independent residential units. While primarily for acoustic comfort, the density and type of the insulation materials shown here contribute to the overall internal thermal mass calculations of the building zones.

APPENDIX E – Survey Questionnaire & Answers

Q1. In winter, I need mechanical heating. (1 = rarely, 5 = always)

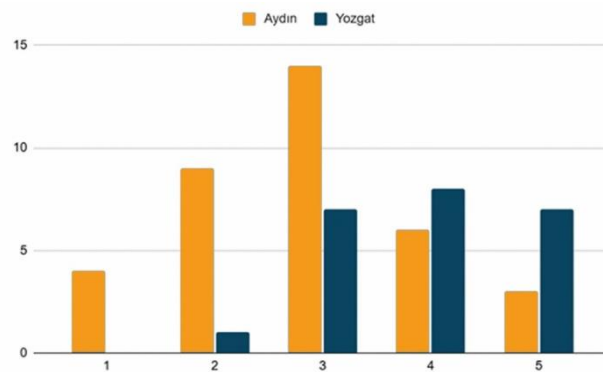


Figure 40. Thermal comfort responses regarding heating needs during winter (Aydın / Yozgat TOKİ).

Q2. In summer, I need mechanical cooling. (1 = rarely, 5 = always)

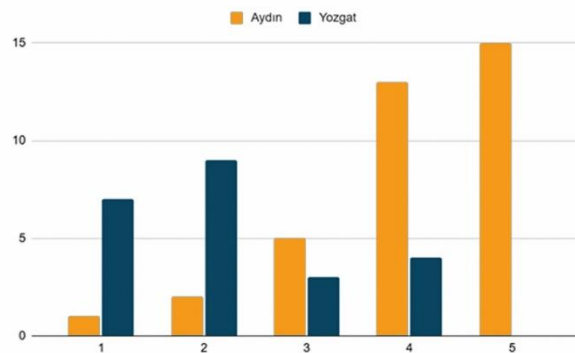


Figure 41. Thermal comfort responses regarding cooling needs during summer (Aydın / Yozgat TOKİ).

Q3. Have you personally made any changes to improve the thermal comfort in the home during the winter months? Yes / No

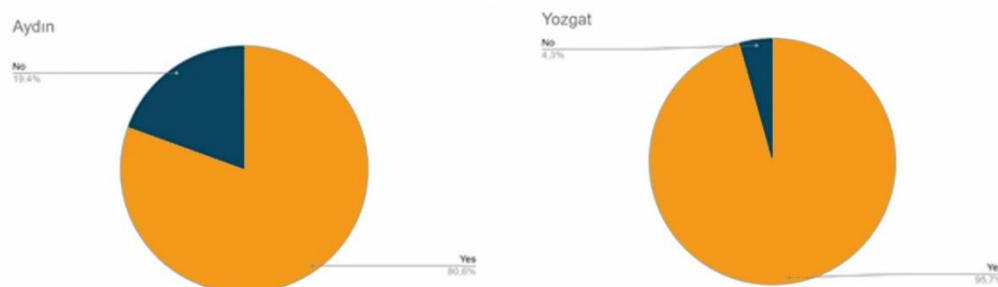


Figure 42. Reported personal measures to improve thermal comfort during winter (e.g., carpets, thick curtains, window bands, insulation) (Aydın / Yozgat TOKİ)

Q4. Have you personally made any application to increase the coolness in the house during the summer? (For example: curtain use, window film bonding, furniture arrangement to improve airflow, canopy-tents installation, shutters, air condition) Yes /No

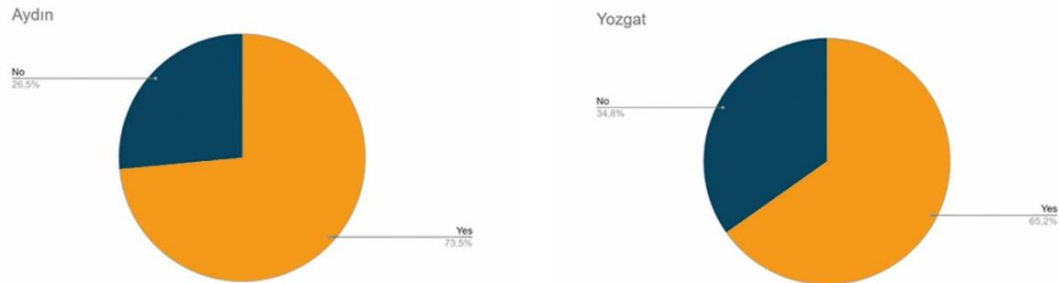


Figure 43. Reported personal measures to enhance indoor cooling and comfort during summer (e.g., curtains, window films, shading devices, furniture arrangement, air conditioning) (Aydın / Yozgat TOKİ).

Q5. In which room(s) do you feel uncomfortable in terms of temperature? (If any)

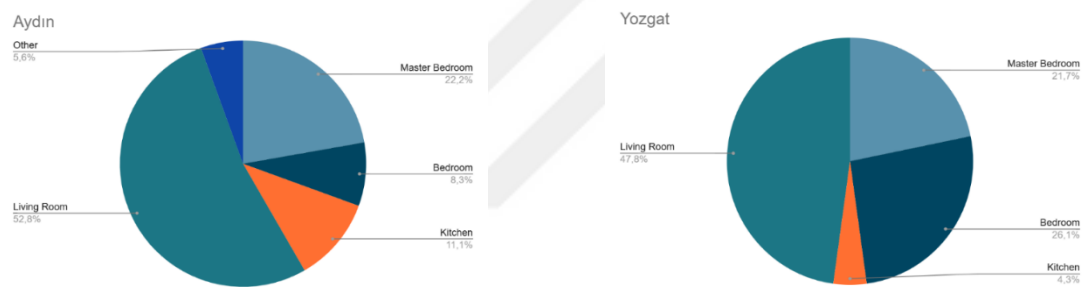


Figure 44. Reported rooms where residents experience thermal discomfort (e.g., living room, bedroom, kitchen) (Aydın / Yozgat TOKİ).

Q6. My home receives enough natural sunlight during the day. (1 = disagree, 5 = agree)

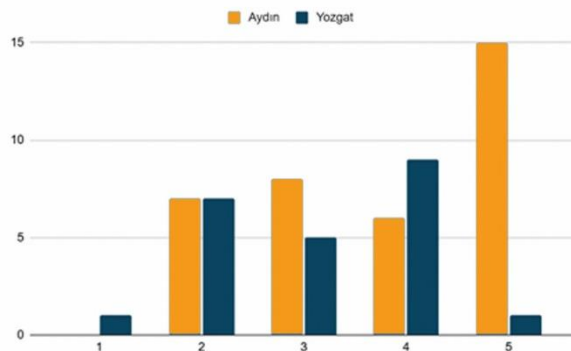


Figure 45. Residents' perceptions of daylight sufficiency throughout the day (Aydın / Yozgat TOKİ).

Q7. I use artificial lighting in some rooms during the day due to insufficient daylight.
(1 = disagree, 5 = agree)

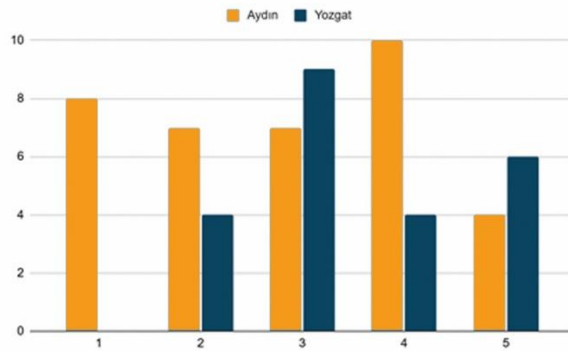


Figure 46. Frequency of artificial lighting use during daytime due to insufficient daylight in certain rooms (Aydın / Yozgat TOKİ).

Q8. Have you personally made any changes in your home to increase or reduce sunlight exposure? Yes / No

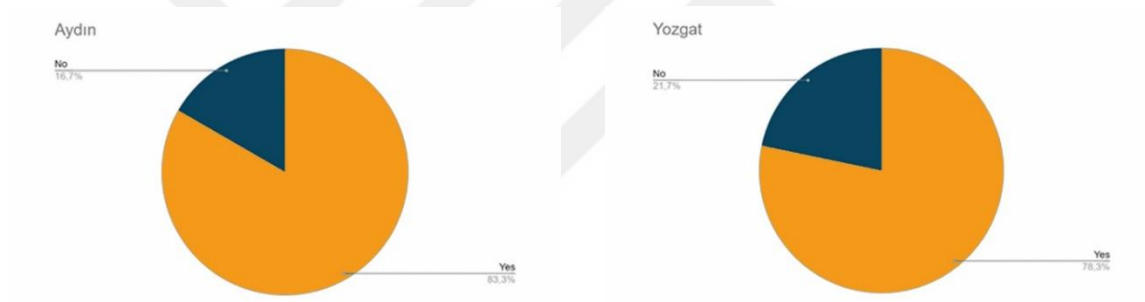


Figure 47. Reported personal adjustments to control or optimize solar access and daylight usage (e.g., curtain use, blinds, window films, furniture arrangement) (Aydın / Yozgat TOKİ).

Q9. How satisfied are you with the indoor air quality in your home and the performance of the ventilation system (natural or mechanical) in meeting your needs? (1 = not at all pleased, 5 = very pleased)

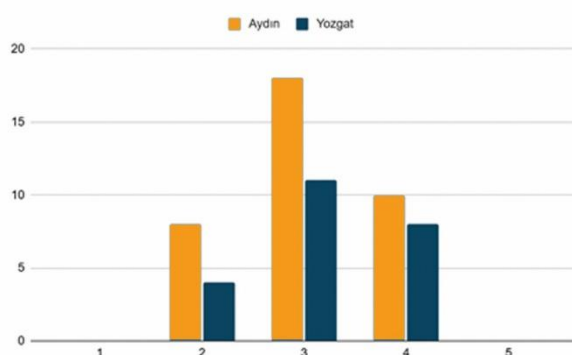


Figure 48. Residents' satisfaction with indoor air quality and the performance of natural or mechanical ventilation systems (Aydın / Yozgat TOKİ).

Q10. Is smoking allowed inside your home? Yes / No

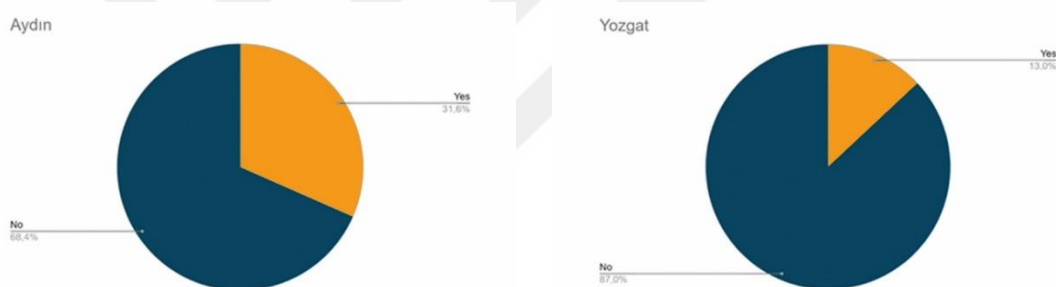


Figure 49. Smoking prevalence within households as a factor influencing indoor air quality (Aydın / Yozgat TOKİ).

Q11. Have you noticed any issues with the building envelope over time (e.g., cracks, leaks, aging)? Yes / No



Figure 50. Reported defects or visible deterioration in the building envelope (e.g., cracks, leaks, surface wear) (Aydın / Yozgat TOKİ).

Q12. Do you observe mold, blackening or moisture formation in your home on surfaces near exterior walls, window edges or ceiling corners? Yes / No

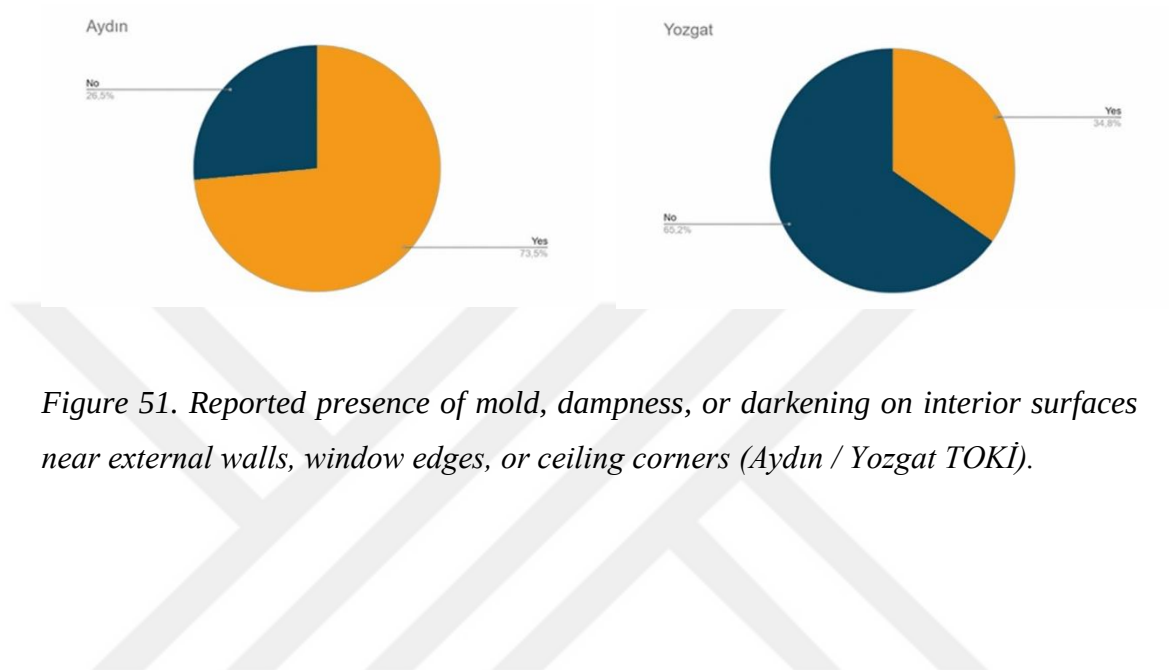


Figure 51. Reported presence of mold, dampness, or darkening on interior surfaces near external walls, window edges, or ceiling corners (Aydın / Yozgat TOKİ).

APPENDIX F - Simulation Input Parameters

This appendix compiles the key simulation inputs and model assumptions used in the parametric performance analysis conducted in Grasshopper tools. The goal is to provide full transparency regarding how the digital evaluation environment was structured.

Table 8. Building Performance Simulation Inputs

Input Category	Description
Climate Data	EPW files for Aydin and Yozgat obtained from EnergyPlus weather database
Building Geometry	Modeled using standardized 2+1 apartment type; parametric surfaces defined for each element.
Site Context	External surrounding buildings were modeled based on site plan and imported into simulation.
Orientation	North orientation based on original project documents.
Shading Consideration	Contextual shading from adjacent buildings included in simulation.
Wall Construction	Wall thickness modeled; no layered insulation materials entered separately.
Roof Construction	Roof generated automatically with 33% slope via parametric logic.
Internal Partitions	Interior walls modeled for spatial and thermal zoning.
Interior Doors	Interior doors were excluded from the simulation model.
Window Modeling	Windows defined according to base model dimensions; materials not assigned, treated as openings.
Balconies	Balconies were modeled and included in the simulation geometry.
Thermal Zones	Four zones defined: living room, kitchen, bedroom, and bedroom.
Simulation Period	Annual simulation with hourly resolution using Ladybug/EnergyPlus engine.
Heat System	Deactivated in model to reflect passive conditions (no HVAC input).
Occupancy and Loads	Default residential schedules assumed (internal gains not separately customized).
Infiltration/Ventilation	Default airtightness; no mechanical ventilation modeled.
Daylight Metrics	DA (300 lux, 50%), UDI (100–2000 lux ideal range).
Thermal Comfort Metric	UTCI index (Universal Thermal Climate Index) applied to zones.
UTCI Stress Thresholds	• No Thermal Stress: 18°C to 26°C • Moderate Heat Stress: 26°C to 32°C • Strong Heat Stress: 32°C to 38°C • Extreme Heat Stress: >38°C • Moderate Cold Stress: 9°C to 0°C • Strong Cold Stress: 0°C to -13°C • Extreme Cold Stress: < -13°C
Sensor Grid Settings	Sensor points automatically distributed on floor surfaces; grid resolution based on room size.

Aydin and Yozgat simulations used the same building geometry to isolate climatic influence. However, surrounding blocks were modeled uniquely for each city based on their own TOKI site plans. This allowed contextual shading differences to be accounted for during simulation.

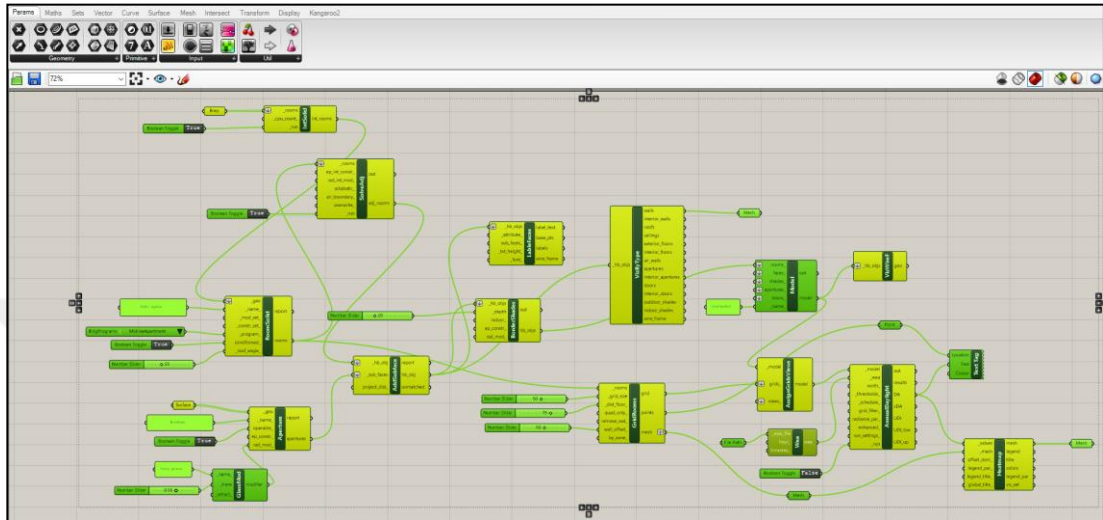


Figure 52. Simulation Setup in Grasshopper

User interface showing the parametric model structure used for geometry generation, zoning, and simulation control. The definition includes climate inputs, building components, and analysis parameters integrated with Ladybug and Honeybee plugins.

APPENDIX G - Useful Daylight Illuminance (UDI) Distribution

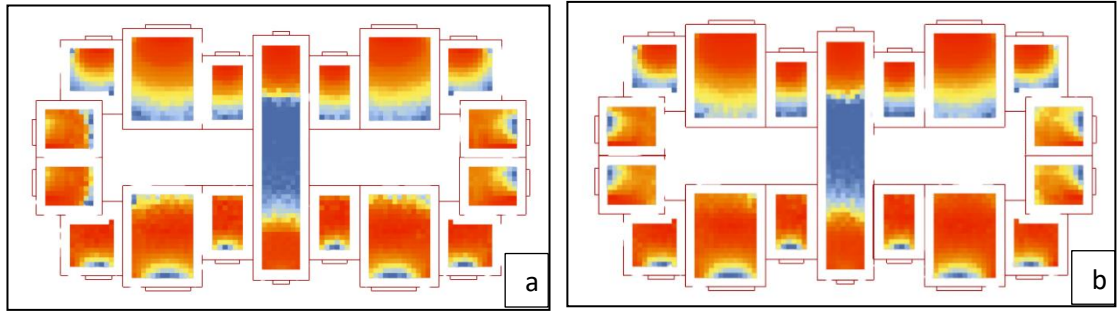


Figure 53. Annual Useful Daylight Illuminance (UDI) distribution analysis of the Aydın (a) and Yozgat (b) floor plan of reference block.

This comparative analysis reveals how identical building typologies behave differently under site-specific constraints. Aydın exhibits a distinct 'directional asymmetry,' where the West wing suffers from steep daylight gradients due to neighboring shading masks. In contrast, Yozgat maintains a 'balanced distribution,' achieving consistent useful daylight penetration on both East and West axes. A significant anomaly is detected in Aydın, where the South perimeter is interrupted by 'blue patches,' indicating that external obstructions block potential solar gain. Yozgat, however, shows uninterrupted high-intensity access, maximizing passive heating potential.

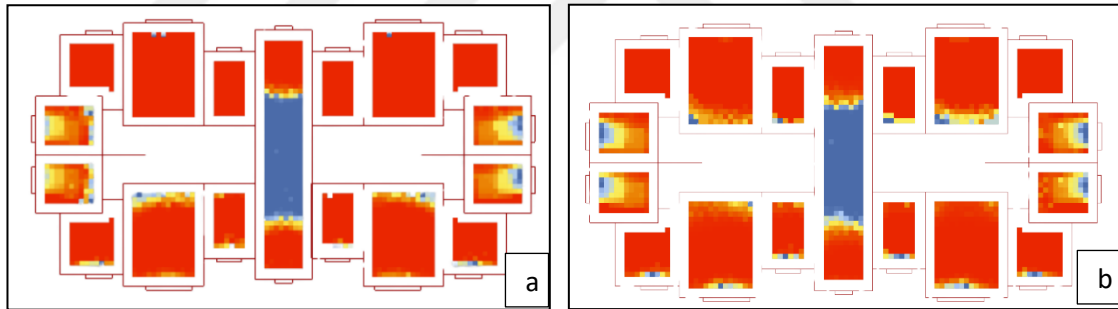


Figure 54. Seasonal (summer) Useful Daylight Illuminance (UDI) distribution analysis of the Aydın (a) and Yozgat (b) floor plan of reference block.

A critical anomaly is observed in Aydın, particularly on the East façade. The perimeter zones exhibit lower performance scores (Yellow) compared to the deeper room areas. This 'Inverse Gradient' confirms that solar intensity at the window exceeds the useful threshold (>2000 lux), causing severe glare rather than providing functional illumination. In contrast, Yozgat maintains high performance (Red) at the perimeter, indicating 'bright but controlled' penetration. However, this control comes with a limitation: the plan exhibits a 'Sharp Cutoff,' where useful daylight drops rapidly to zero (Blue Zones) towards the rear walls, necessitating artificial lighting even in summer. Consistent with previous findings, Aydın displays strong asymmetry (glare-prone East vs. limited West), while Yozgat maintains a balanced, symmetrical performance across both wings.

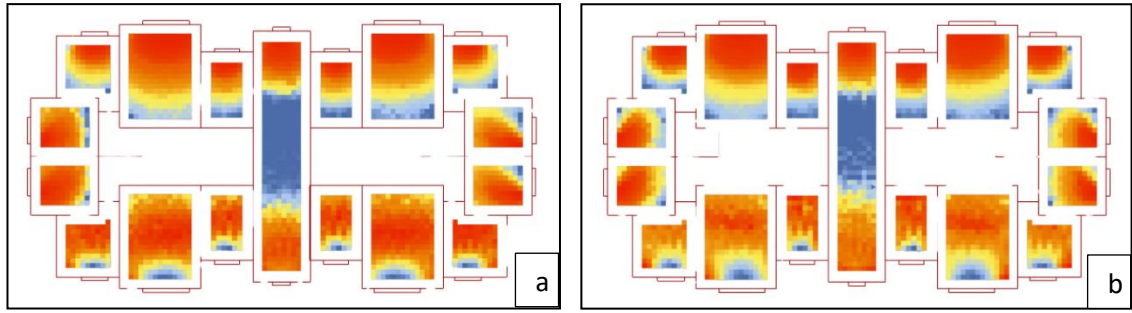


Figure 55. Seasonal (winter) Useful Daylight Illuminance (UDI) distribution analysis of the Aydın (a) and Yozgat (b) floor plan of reference block.

In both climatic zones, the South wing exhibits exemplary performance. Deep 'Red/Orange' zones confirm that low-angle winter sun penetrates deep into the room while remaining within the useful range (100–2000 lux). This maximizes passive heating potential—crucial for Yozgat—without the glare risks observed in summer. A severe deficiency is observed on the North face, where useful daylight is strictly confined to a narrow perimeter strip. The diffuse skylight is insufficient to illuminate the room depth, necessitating artificial lighting. On the lateral wings, useful daylight is visibly 'compressed' towards the windows. This is caused by elongated shadows from neighboring blocks, which obstruct morning and afternoon sun significantly more in winter than in summer, limiting effective autonomy to the building envelope.

APPENDIX H - Ethical Board Approval



T.C.
Sosyal ve Beşeri Bilimler Etik Kurulu



No : E-97429853-050.04- 114474
Subject : Ethics Committee Decision

29.12.2025

DEAR DR.ÖĞR.ÜYESİ ATHANASIOS STASINOPOULOS

Your application for the ethical approval of the project titled "*Passive Energy Design in Residential Buildings in Türkiye: A Case Study of TOKI Housing in Two Climatic Zones*" has been evaluated. The details of your application have been reviewed. As a result, it was decided that your research project titled "*Passive Energy Design in Residential Buildings in Türkiye: A Case Study of TOKI Housing in Two Climatic Zones*" is ethically appropriate.

For your kind attention.

Prof. Dr. Murat BENGİSU
Kurul Başkanı

Verify Code :BSL35EJDN8

To Verify Documents : <https://turkiye.gov.tr/izmir-ekonomi-universitesi-ebys>

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