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Assoc. Prof. Hüseyin Samet Aşıkkutlu, Ph.D.
Assoc. Prof. Orhun Soydan, Ph.D.

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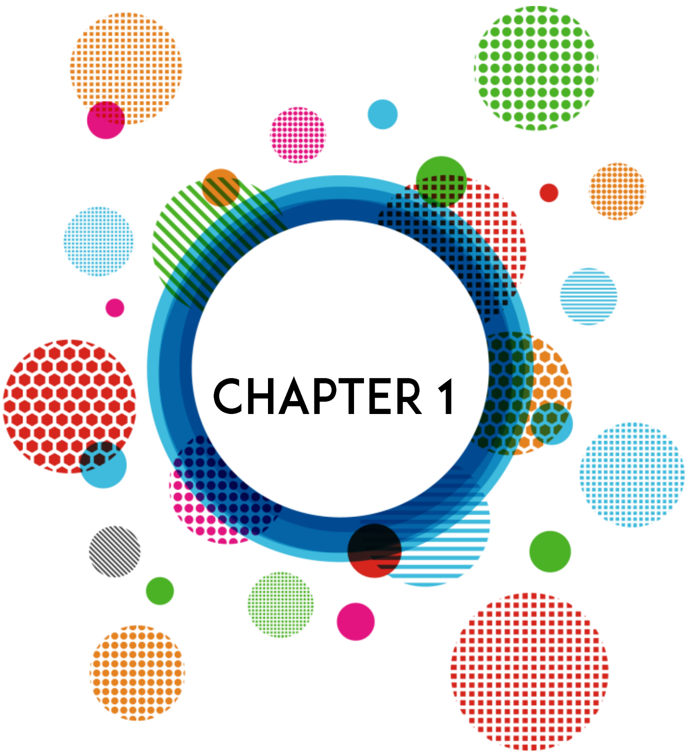

Climate Change and Gender Equality: Non-Governmental Organizations as Catalysts for Climate Change*

Mercan Efe Güney[1] & Elif Su Karaaslan[2]

* This study has been developed through the refinement of the projects conducted during the Fall Semester of the 2024-2025 Academic Year for the PLN 6015 Conceptual Investigations in Planning course, which is part of the PhD Program in City and Regional Planning at Dokuz Eylül University, Graduate School of Natural and Applied Sciences

[1] Prof. Dr., Dokuz Eylül University, Faculty of Architecture, Department of Urban and Regional Planning, ORCID: 0000-0001-8498-4796

[2] M.Sc., Dokuz Eylül University, Graduate School of Natural and Applied Sciences ORCID: 0000-0003-3121-4426

1. INTRODUCTION

Non-governmental organizations (NGOs) are voluntary entities that operate independently from the state and aim to address various social challenges. These organizations are key agents in initiating and sustaining change, particularly in advancing gender equality and responding to a wide array of societal and environmental issues. By promoting democratic participation, bridging the gap between state and society, and demonstrating agility and responsiveness in times of crisis, NGOs have significantly contributed to raising awareness and resolving pressing global problems (Diamond, 1994; Giorgetti, 1998; Haris et al., 2021; Heper, 2001; Keck & Sikkink, 1998; Putnam, 1993; Salamon & Anheier, 1996).

NGOs, while active in many domains, have become particularly prominent in the climate change arena for their role in raising awareness and influencing policy processes. Climate-focused NGOs contribute by promoting public awareness (Doyle, 2007), advocating for and shaping policies (Betsill & Corell, 2001), producing and disseminating scientific knowledge (CAN, 2022), organizing local and global mobilizations (De Moor et al., 2020), and holding governments and corporations accountable (Newell, 2000).

Climate change poses unprecedented global challenges, driven primarily by human activity (Talu, 2017). Increasing attention has been directed toward issues such as resilience, vulnerability, disaster risk reduction, food security, and sustainable agriculture. Although climate change is a societal issue, its impacts are not distributed equally. Gender inequality plays a critical role in shaping both vulnerability and adaptive capacity (Eastin, 2017; Pinho-Gomes & Woodward, 2024).

Studies at both global and national levels consistently show that women are disproportionately affected by the impacts of climate change (Castañeda Carney et al., 2020; MacGregor, 2010; Neumayer & Plümper, 2007; UN Women, 2018). This disparity stems primarily from gender-based roles. Climate-related phenomena—such as droughts, floods, and deforestation—disrupt women’s responsibilities in securing family well-being and food security (Eastin, 2018; UN Women, 2018). In addition, political and economic inequalities limit women’s access to land ownership, credit, and productive resources, further increasing their vulnerability and diminishing their adaptive capacity (FAO, 2011). One stark indicator of this inequality is the higher mortality rate of women during natural disasters (Neumayer & Plümper, 2007). Climate change also aggravates health risks for women, including increased exposure to infectious diseases, malnutrition, and lack of access to clean water—especially for pregnant women (WHO, 2014). Furthermore, climate-induced migration places women, particularly those migrating with children, at greater risk of gender-based violence, economic exploitation, and restricted access to basic rights (Castañeda Carney et al., 2020).

Thus, women are disproportionately vulnerable to the effects of climate change (Haris et al., 2021; Yu, 2022). Socially constructed gender roles, economic dependency, and exclusion from decision-making processes increase their exposure to risks while limiting their ability to respond. In this context, civil society organizations that prioritize women's roles in climate action play a vital role. These organizations amplify the voices of women, empower them as agents of change, and contribute to the formulation of inclusive and sustainable climate policies that promote gender justice.

This study aims to explore the efforts of civil society organizations in implementing projects that address both climate change and gender equality. By identifying the geographic distribution and objectives of these projects, the study seeks to reveal their spatial scope and thematic orientations.

2. METHODOLOGY

This study examined the spatial distribution of projects implemented by NGOs, the time periods during which these projects were carried out, the potential causes of temporal clustering (if any), whether the projects were primarily conducted in developed or developing countries, and the thematic areas addressed beyond climate change and gender equality.

Data collection took place in December 2024 and consisted of two phases. In the first phase, the websites of non-governmental organizations were reviewed to identify those focusing on both gender equality and climate change. In the second phase, the websites of the selected organizations were examined in greater detail to analyze specific projects aligned with these themes. Table 1 presents the evaluation criteria used to analyze projects addressing climate change and gender equality.

Table 1. Categories of the Project's Dataset

NGO	Name Of The NGO
	Foundation Year
	Region (Global, Local)
Project	Name of the Project
	Year of the Project
	Country, City
	Aim of the Project
	Partnership (If any)
	Policy Theme (Climate Change, Gender Equality, Climate Change & Gender Equality or Other)
	Completion Status (Not Started, Continuing, Completed)

This table summarizes the project-level variables used to evaluate and categorize initiatives focused on climate change and gender equality. In addition, the study conducted a spatial analysis using geographic information from the projects (when available). Since some projects were implemented in multiple locations, a single project may be represented in more than one area. For the spatial visualization of project locations, the open-source GIS software QGIS was utilized to map the initiatives based on their actual geographic coordinates.

3. FINDINGS

This section presents the findings derived from the analysis of non-governmental organizations and their projects focusing on climate change and gender equality.

3.1. Overview of the Non-Governmental Organizations and Their Project Information

The study identified eight non-governmental organizations that have implemented relevant projects. These organizations operate at a global scale rather than solely national levels. Table 2 lists these NGOs along with their foundation years, the number of analyzed projects, and the number of project locations focused on gender equality and climate change.

Table 2. List of Examined NGOs

Name of the NGO	Foundation Year	Geographic Scope	Number of Analyzed Projects	Number of Project Location
CARE International	1945	Global	7	8
OXFAM International	1995	Global	12	22
Global Fund for Women	1987	Global	2	46
ActionAid	1987	Global	9	17
ICLEI – Local Governments for Sustainability	1990	Global	8	25
Global Gender and Climate Alliance (GGCA)	2007	Global	7	3
The Green Climate Fund (GCF)	2010	Global	30	123
Women's Earth and Climate Action Network (WECAN)	2013	Global	5	18
Total			**80**	**262**

As shown in Table 2, these eight NGOs implemented a total of 80 projects related to gender equality and climate change, spanning 262 distinct locations worldwide.

Of these, 54 projects have been completed, 23 are ongoing, and 3 are planned. The distribution of project statuses is visualized in Figure 1. Figure 1 illustrates that ongoing projects represent the majority (68%) of all recorded initiatives. Completed and planned projects constitute 29% and 3%, respectively.

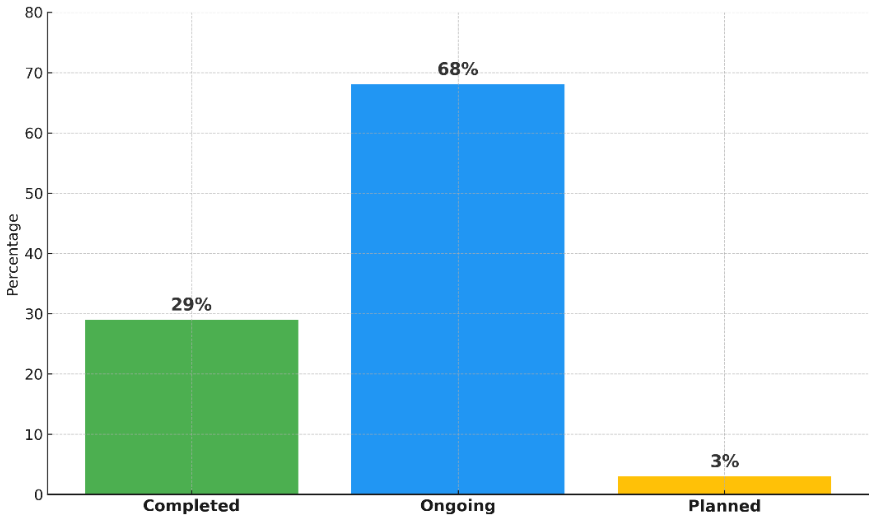

Figure 1. The Statuses of the Projects (%)

The high percentage of ongoing projects suggests a strategic focus on active implementation and resource allocation. Below, Table 3 summarizes project status distribution and interpretative insights for each NGO.

Insights derived from the systematic analysis of project status distributions across each NGO are outlined below.

Global Gender and Climate Alliance (GGCA) and the **Women's Earth and Climate Action Network (WECAN)** exhibit high levels of project completion, with completed projects comprising approximately **85–90%** of their respective portfolios. This prevalence of finalized initiatives may suggest organizational maturity, efficient project cycles, or retrospective funding structures aligned with deliverables over time.

In contrast, **The Green Climate Fund (GCF)** and **CARE International** show a clear emphasis on active implementation. Ongoing projects represent nearly **70–75%** of their total engagements, indicating these organizations are currently in operational phases. This pattern may also reflect recent strategic scaling or alignment with global climate financing trends that prioritize adaptive and transformative gender-responsive programming.

ActionAid presents a more evenly distributed profile, with *completed* and *ongoing* projects each constituting roughly **45–50%** of its project base. This balance suggests a continuous cycle of programmatic activity, possibly indicative of strong institutional stability and the presence of overlapping implementation timelines.

OXFAM International, on the other hand, shows a marked concentration of *planned* and *ongoing* initiatives, jointly accounting for more than **60%** of its current project profile. This may reflect a recent pivot in organizational strategy or increased funding commitments aimed at future-oriented gender-climate interventions.

The **Global Fund for Women** appears to engage in a more focused and condensed implementation strategy, with a relatively smaller number of projects that are predominantly *completed* (**over 80%**). This compact yet targeted distribution likely reflects shorter funding cycles, niche interventions, or a narrower geographic or thematic scope.

Finally, **ICLEI – Local Governments for Sustainability** demonstrates a forward-leaning operational profile, with *ongoing* and *planned* projects together comprising **approximately 90%** of its total activities. This orientation underscores ICLEI's commitment to anticipatory urban governance, emphasizing local-level climate action where gender considerations are integrated into sustainable city development frameworks.

In conclusion, while there is notable variability in the volume and status of projects across these organizations, certain patterns emerge. Organizations such as GGCA and WECAN appear more retrospective in project outcomes, whereas GCF, CARE, and ICLEI exhibit strong forward-leaning portfolios. These distinctions reveal not only different temporal strategies but also possibly distinct institutional mandates, funding mechanisms, and regional or thematic emphases within the broader global movement addressing gender and climate justice.

The number of completed and ongoing projects by year for each non-governmental organization examined is presented in Figure 2.

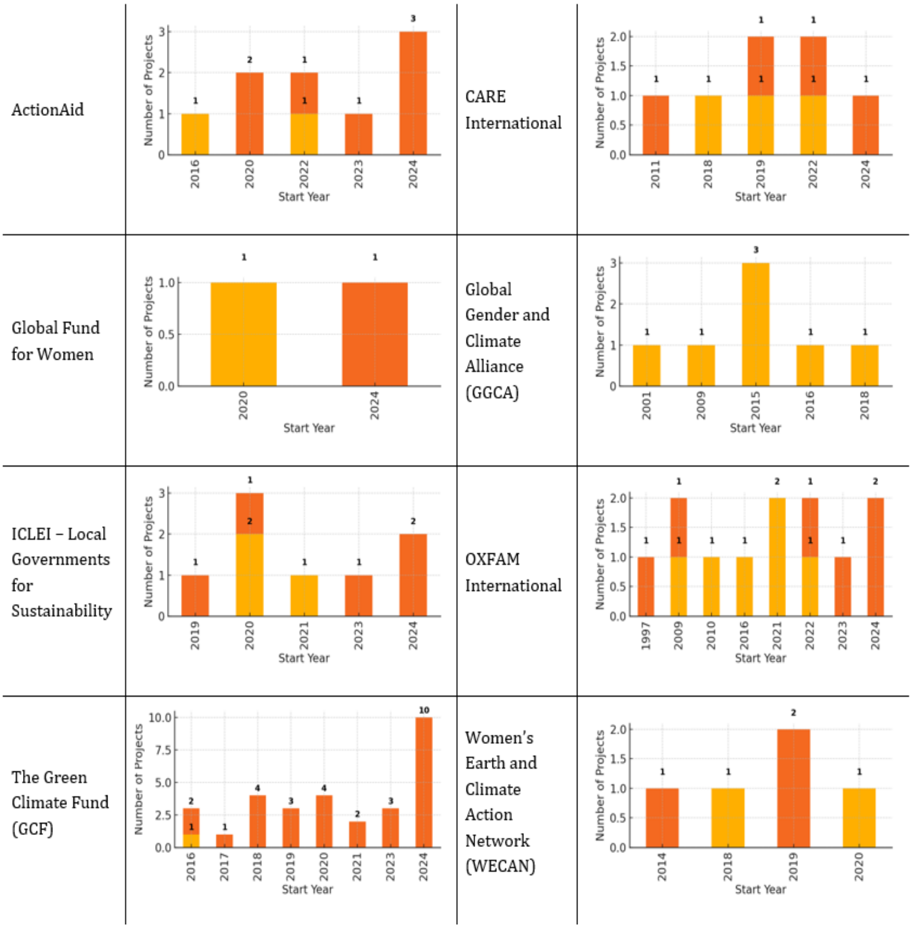

Figure 2. NGO's Project Status by Year

The information presented in Figure 2 is summarized in Table 3 for each non-governmental organization.

Table 3. NGO Project Distribution

NGO	Project Focus Distribution	Interpretation
Global Gender and Climate Alliance (GGCA)	85–90% Completed	Mature, efficient project cycles
Women's Earth and Climate Action Network (WECAN)	85–90% Completed	Mature, efficient project cycles
The Green Climate Fund (GCF)	70–75% Ongoing	Active implementation; recent scale-up
CARE International	70–75% Ongoing	Active implementation; recent scale-up
ActionAid	45–50% Completed, 45–50% Ongoing	Balanced and stable programmatic flow
OXFAM International	60% Ongoing & Planned	Strategic pivot to future-oriented projects
Global Fund for Women	80%+ Completed (Fewer Projects)	Compact, targeted interventions
ICLEI – Local Governments for Sustainability	90% Ongoing & Planned	Future-oriented, anticipatory urban focus

In Figure 3, each bar represents the number of projects that were active in a given year, encompassing both the initiation and continuation phases where applicable.

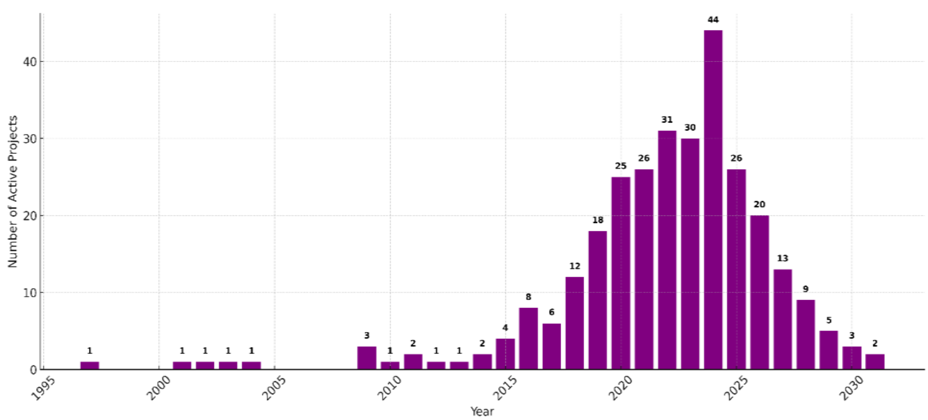

Figure 3. Annual Distrubition of Active Projects Based on Duration

The visual reveals clear patterns of project intensity over time. A notable concentration of projects is observed between 2014 and 2018, indicating a period of heightened institutional engagement with gender and climate-related initiatives. This may reflect an increased global policy emphasis during those years, potentially linked to milestones such as the Paris Agreement (2015) or the Sustainable Development Goals (2015), which catalyzed funding and implementation efforts in these sectors.

Earlier years, such as the early 2000s, show relatively lower levels of activity, which may suggest that institutional involvement in gender-climate intersections was still emerging. In contrast, the post-2020 period shows a slight tapering, possibly due to data limitations, reporting delays, or project planning cycles not yet captured in the dataset.

Overall, the figure offers a clear depiction of when NGOs have been most active in implementing relevant projects. It also provides a useful basis for correlating project timing with global policy developments, funding availability, and organizational growth trajectories.

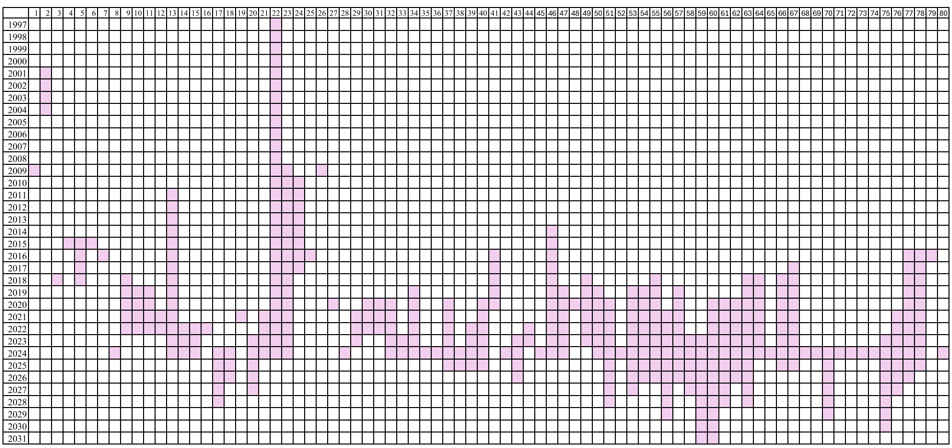

Figure 4. Durations of the Projects

Figure 4 illustrates the distribution of project initiation years across all recorded initiatives. Each row represents a unique project, while each column corresponds to a specific calendar year. The visual allows for the identification of temporal clustering, revealing higher densities of project initiations during certain periods—most notably between 2016 and 2023. This clustering likely corresponds to increased global and institutional emphasis on gender-responsive climate action following major policy frameworks such as the Paris Agreement and the UN Gender Action Plan. Lighter cells indicate individual project starts, while darker aggregations suggest periods of heightened activity. Such visualizations assist in temporal analysis of civil society engagement patterns and can guide evaluations of alignment with global policy developments.

3.2. Policies of the Projects

The projects were evaluated under various categories as mentioned earlier. Policy themes predetermined under 3 main groups and 1 ‘Other’ choice. Projects listed according to the themes are presented in Table 4.:

As presented in Table 4, the majority of the analyzed projects are categorized under the combined theme of *Climate Change & Gender Equality*, comprising 62 initiatives. This is followed by 43 projects labeled as *Other*, 14 projects focused solely on *Climate Change*, and a smaller segment of 4 projects centered on *Gender Equality*. The data suggests that most interventions take an integrated approach, addressing climate and gender dimensions simultaneously rather than treating them as isolated areas of concern.

Table 4. Project Count Table by Policy Theme

Policy Theme	Number of Projects
Climate Change	14
Gender Equality	4
Climate Change & Gender Equality	62
Other	43

Figure 5 provides a visual representation of the same data, illustrating the number of projects per policy theme using a vertical bar chart. Although the *Climate Change & Gender Equality* category clearly dominates in project count, the substantial presence of the *Other* category indicates that several initiatives may incorporate alternative or cross-cutting themes not explicitly defined within the core classification. The relatively limited number of projects focusing exclusively on *Gender Equality* may point to a gap in targeted programming in that area or reflect integration within broader frameworks.

Together, Table 4 and Figure 5 highlight the thematic orientation of project efforts and suggest a strong institutional emphasis on the intersectionality of climate and gender issues in the design and implementation of civil society interventions.

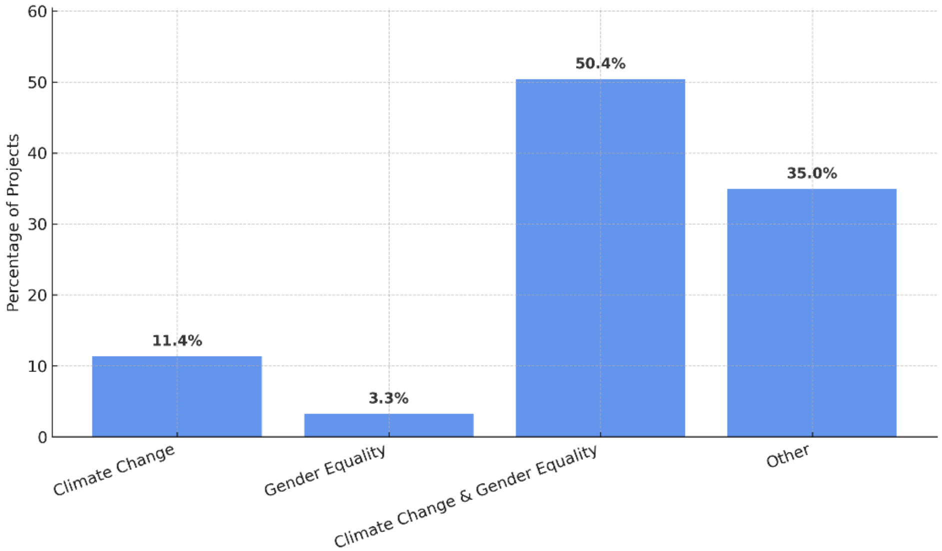

Figure 5. Project Distribution by Policy Theme (%)

Some projects have various dimension in terms of theme. So, the 'Other' option examined deeply and the following Table 5. Presented the most common other themes alongside the 3 main categories:

Table 5. Most common 'other' themes

Other Themes in Detail	Number of Projects
Food Systems, Food Security	2
Agriculture	18
Disaster	12
Biodiversity	1
Social Justice	3
Education	2

The most prominent observation in Table 5 is the notably high number of projects related to agriculture. This finding suggests that a considerable portion of initiatives addressing climate change and gender equality also target the agricultural sector. As highlighted in the literature review of this study, women play a critical role in agriculture-based economies. Numerous studies have emphasized that, particularly in developing countries, women constitute a substantial segment of the agricultural workforce—often participating in informal and unpaid labor. Rural women, in particular, are among the groups most severely affected by climate change. Due to their traditional roles as primary users of natural resources and their reliance on subsistence farming, rural women are disproportionately vulnerable to environmental degradation and climate-induced resource scarcity (Talu, 2017).

Furthermore, Table 5 indicates a significant presence of projects focused on disaster-related themes in addition to those addressing climate change and gender equality. While natural disasters cannot be entirely prevented, their risks can be mitigated through strategic research, planning, and preparedness. Vulnerable populations—especially women, children, and the elderly—are often the most severely impacted in disaster-prone regions. Therefore, the integration of disaster risk reduction into gender-focused climate initiatives represents a progressive and necessary approach toward building inclusive resilience strategies.

3.2. Spatial Context of the Projects

The geographic distribution of projects implemented by the eight NGOs was also analyzed to understand spatial trends. Figure 6 visualizes these locations using a global map with color-coded markers to denote the type and presence of project activity.

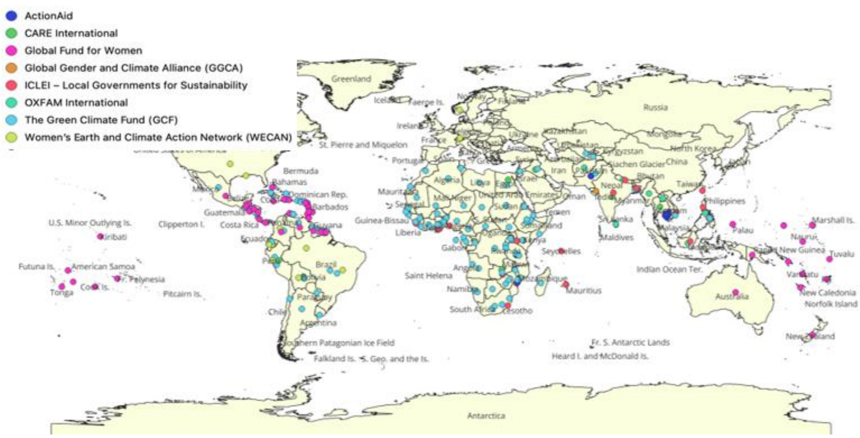

Figure 6. Spatial Locations of the Projects Carried out by NGOs

The spatial analysis reveals several key geographic patterns:

1. **High-Density Clusters:**

- Sub-Saharan Africa (e.g., Kenya, Uganda, Ghana, Nigeria, Mozambique)

- South and Southeast Asia (e.g., India, Nepal, Bangladesh, Philippines)

- Central America and the Caribbean (e.g., Guatemala, Haiti, Dominican Republic)

These areas reflect both the development priorities of NGOs and the high vulnerability of local populations.

2. Dispersed Presence in Small Island Developing States (SIDS): Projects in Pacific Island nations such as Kiribati, Tonga, and the Marshall Islands highlight targeted climate resilience efforts in highly vulnerable regions.

3. Comparative Absence: Regions like Northern and Eastern Europe, Russia, and parts of China show relatively fewer NGO interventions, possibly due to restricted civil society access or alternative national development agendas.

4. Institutional Reach: The widespread presence of these NGOs across continents reflects their strong operational capacity and alignment with international development agendas such as the SDGs and the Paris Agreement.

The spatial mapping presented in Figure 6 indicates that civil society engagement is not random but rather strategically deployed in regions of elevated climate and gender-based vulnerability. These findings underscore the role of NGOs in extending climate and gender-responsive interventions to communities that are often marginalized within top-down policy frameworks (Gaard, 2015; Röhr, 2018).

As the findings of this study demonstrate, a significant concentration of NGO projects addressing climate change and gender equality are implemented in developing regions, particularly in the Global South. This trend reflects broader structural vulnerabilities. Research has increasingly confirmed, and policy discussions widely acknowledge, that climate change disproportionately affects the world's poorest regions, where socially disadvantaged groups—especially women—bear the heaviest burdens (Röhr et al., 2009). These vulnerabilities are compounded by socioeconomic inequalities and limited access to resources, institutions, and decision-making platforms.

One of the primary factors contributing to this disparity is the unequal distribution of unpaid household labor, which remains a persistent norm in many developing societies and increases women's exposure to climate-related risks (Eastin, 2017). Furthermore, the prevalence of patriarchal legal and social systems in these regions exacerbates gender-based vulnerabilities and constrains women's adaptive capacity (Eastin, 2017). These findings reinforce the need for NGO-led interventions that not only respond to environmental crises but also address the systemic gender inequalities that heighten climate vulnerability.

4. CONCLUSION

In this study, the projects addressing climate change and gender equality carried out by non-governmental organizations worldwide are investigated and analyses are conducted to answer the research questions.

The websites of the non-governmental organizations producing studies and projects on climate change and gender equality are deeply investigated. So, the data collection primarily prepared based on the research conducted on the web in December, 2024. In addition, examining the spatial distribution of the non-spatial project information obtained in this study is crucial for evaluating a different dimension. To perform a spatial analysis, the location information of each project (if available) was collected manually.

When the overall themes of the projects are examined, it is observed that, in addition to focusing on climate change and gender equality, the projects also develop strategies and initiatives related to agricultural production activities and disasters.

The years that projects are conducted analyzed using basic statistics, and found that, a significant increase in the number of projects is evident, particularly from 2014 onwards, reflecting a sharp upward trend. This suggests that the importance given to gender equality in climate change-related efforts has accelerated significantly in the years following the 2010s. It is concurrent with the findings and statements of Rainard (2023) and Talu (2017).

When the geographical distribution is examined, it can be stated that the projects are generally carried out and concentrated in the Southern Hemisphere and developing countries.It is concurrent with the statements of Eastin (2017), Talu (2017) and Röhr et al. (2009). They pointed out the real struggle in developing countries, the risks they had against the climate change, and especially the vulnerable ones, women. So, the researches, studies, projects must really concentrate on these areas where the climate crisis hit so hard.

It is understood from this study that, despite being a significant part of production, family, and social life, women have consistently been marginalized. This situation has led to women, children, and other disadvantaged groups in society being vulnerable to environmental impacts. (Kutlu, 2024) also stated that gender-based power dynamics limit women's participation in decision-making processes, restrict their access to information, productive resources, and financial means, and constrain their mobility.

Climate change planning and policy decision-making is predominantly male-driven, which likely explains why climate policies tend to prioritize traditionally male livelihoods and economic activities over the care economy, where women play a dominant role (Röhr et al., 2009). Considering the diverse negative effects of climate change, it is evident that women are disproportionately exposed to these adverse impacts in every area where they are actively involved in society. Srivastava and Austin (2012) also stated that leading international institutions backing development programs have established and supported gender policies that emphasize the active involvement of women in decision-making and their empowerment. Moreover, When women are granted positions of power in society, it is thought to enhance their inclination to protect and preserve the environment (Mckinney & Fulkerson, 2015).

Lastly, Sen and Grown (1988) noted that, "Equality for women is impossible within the existing political, cultural processes that reserve resources, power and control for small groups of people. But neither is development possible without gender equality for, and participation by, women" (as cited by Srivastava & Austin, 2012, p. 11).

An examination of project implementation timelines reveals a notable intensification during the 2014–2018 period. This increase aligns closely with several key international developments in gender and climate policy that likely contributed to the observed project surge.

1. The Lima Work Programme on Gender (2014): In 2014, the UNFCCC launched the Lima Work Programme on Gender (LWPG), aiming to enhance gender balance and to ensure gender-responsiveness in climate policy and actions. The program established a foundation for integrating gender considerations into all aspects of climate governance (UNFCCC, 2014).
2. The Paris Agreement and the Sustainable Development Goals (2015): The adoption of the Paris Agreement in 2015 marked a milestone by explicitly acknowledging the need for gender equality and the

empowerment of women in climate action (UNFCCC, 2015). That same year, the United Nations General Assembly adopted the 2030 Agenda for Sustainable Development, introducing Goal 5 (Gender Equality) and Goal 13 (Climate Action), both of which emphasized cross-sectoral integration and policy coherence (UN, 2015).

3. The Marrakesh COP22 and Continued Emphasis on Gender Integration (2016): The 2016 UN Climate Conference (COP22) in Marrakesh reaffirmed commitments to gender-responsive climate policy. Parties furthered the mandate of the LWPG and initiated dialogue on formalizing gender action through structured frameworks (UNFCCC, 2016).

4. The First Gender Action Plan (2017): At COP23 (in Bonn, Germany), the Gender Action Plan (GAP) was adopted under the UNFCCC framework. The GAP established priority areas such as capacity-building, gender balance in delegations, and policy implementation, signaling a new phase of institutional commitment to gender mainstreaming in climate governance (UNFCCC, 2017; Röhr, 2018).

5. National Policy Development: Cambodia's GAP (2014–2018): At the national level, countries such as Cambodia implemented their own Gender and Climate Change Strategic Plans, integrating gender-responsive approaches into adaptation and mitigation frameworks (FAOLEX, 2015). Such initiatives illustrate how global mandates influenced local policy architectures and project portfolios during this timeframe.

The peak in project activity observed between 2014 and 2018 can thus be contextualized within a broader policy environment that increasingly prioritized gender considerations in climate action. These developments not only shaped funding priorities and institutional strategies but also catalyzed the emergence of integrated, equity-focused project design and implementation models across civil society actors.

As shown in Table 4, civil society organizations (CSOs) have demonstrated a pronounced tendency to design and implement projects that address the intersection of climate change and gender equality simultaneously. The category Climate Change & Gender Equality alone accounts for 62 out of 123 documented projects, indicating a strong institutional orientation toward integrated policy responses. This prioritization reflects a broader global shift in climate governance, where intersectionality is increasingly emphasized as a framework for just and inclusive action (Djoudi et al., 2016; Gaard, 2015).

Figure 5 reinforces this observation by presenting a visual breakdown of thematic focus areas across the dataset. The dominance of integrated projects—over 50% of all recorded initiatives—suggests that NGOs are not only responding to international mandates such as the Paris Agreement (UNFCCC, 2015) and the 2030 Agenda for Sustainable Development (United Nations, 2015), but are also actively engaging in the co-production of equitable climate knowledge and practices at the local level (Nagendra & Ostrom, 2012). This trend reflects the capacity of civil society actors to act as intermediaries between global policy instruments and community-specific vulnerabilities.

While 43 projects fall under the "Other" category—likely encompassing themes such as disaster risk reduction, agriculture, or health—only a limited number of initiatives focus exclusively on Gender Equality (4 projects) or Climate Change (14 projects). This may indicate a strategic preference for holistic project framing, which enhances funding eligibility and policy relevance. As Schalatek (2015) notes, integrated approaches are increasingly favored in global climate finance mechanisms, particularly within institutions like the Green Climate Fund, where gender action plans are mandatory components of project proposals.

Furthermore, CSOs—particularly women-led and grassroots organizations—play a crucial role in ensuring that climate interventions are not only environmentally effective but also socially just. Their local expertise and advocacy power enable them to identify needs that are often overlooked in top-down policy design (Röhr, 2018; Edwards, 2004). The thematic clustering observed in Table 4 and Figure 5 may thus be seen as both a reflection of external funding frameworks and an expression of internal normative commitments among NGOs to inclusive, participatory models of environmental governance.

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CHAPTER 2

Use of Waste-Based Thermal Insulation Materials in Building Envelopes: A Focus On the Turkish Context

Kübra Pir[1] & Kübra Ekiz Barış[2]

[1] Kocaeli Üniversitesi, Mimarlık ve Tasarım Fakültesi, Mimarlık Bölümü, Kocaeli, Türkiye, ORCID: 0009-0003-2175-6018

[2] Dr. Öğr. Üyesi, Kocaeli Üniversitesi, Mimarlık ve Tasarım Fakültesi, Mimarlık Bölümü, Kocaeli, Türkiye, ORCID:0000-0002-3830-7185

1. Introduction

Heat is the energy transferred from one mass to another due to the temperature difference between the two masses. Heat transfer occurs in three ways: (i) Heat conduction is the transfer of thermal energy from one mass to another at a lower temperature through physical contact. It generally occurs in solid materials. (ii) Heat convection is the transfer of heat energy through liquids and gases. (iii) Radiation is the heat flux that occurs when infrared radiation, microwaves, visible light, or any form of electromagnetic radiation is emitted or absorbed. The Sun heats the Earth through radiation (Strother and Turner, 1990).

The building envelope, consisting of the external walls and roof, is the building element where the heat exchange between the building and the external environment is most intense. Therefore, the thermal comfort of a building and the heating and cooling systems used to maintain this comfort, as well as the total energy consumed by these systems, are influenced by the thermophysical properties of the building envelope. With a properly designed building envelope, thermal comfort can be maintained indoors for long periods during the day without using any mechanical systems. Thus, the need for mechanical systems for heating and cooling the building can be kept to a minimum.

Traditional construction materials commonly utilized in the building envelope have a porous internal structure. In these solid-state materials, heat flow occurs largely in the form of conduction. On the other hand, in a material with a pore size smaller than 4 mm, the effect of convection is negligible (Wei et al., 2013). The effect of radiation on heat flow at temperatures below 600 °C can also be neglected (Prud'homme et al., 2015). Therefore, when evaluating the thermal performance of building materials used in the building envelope, heat conduction should be given significant importance. The thermal conductivity of these materials depends on the internal structural properties, and an increase in the porosity significantly reduces the thermal conductivity coefficient (Novais et al., 2016).

To ensure thermal comfort indoors, thermal insulation materials are used in the building envelope to control heat flow through conduction between the indoor and outdoor environments. The thermal conductivity coefficient of thermal insulation materials must be less than 0.1 W/mK (Toydemir et al., 2000). Properly applying thermal insulation to the building envelope prevents issues such as frost damage, moisture damage, and mold. Thus, a comfortable living space for human health is being created, and the building envelope is being made durable (Kulaksızoğlu, 2006).

The excessive energy consumption and the drastic increase in fossil fuel prices, that came with the industrial revolution in the late 19^{th} century, caused an energy crisis worldwide. During this period, as a result of the awareness of energy conservation and the beginning of calculating heat losses, the industrial production and use of thermal insulation materials have begun. In the 1950s, the use of polymer-based materials as thermal insulation increased significantly. Since 2000, due to the awareness of the environmental impacts of the gases used in the production of polymer-based insulation materials, there has been a shift towards the use of natural and sustainable materials (Bozasky, 2010).

The first regulation regarding thermal insulation practices in Türkiye is the TS 825 standard titled "Rules for Thermal Insulation in Buildings," which was adopted on March 6, 1989. With the regulation published in the official gazette numbered 23725 in 1999, this standard became mandatory from 2000. TS 825 was updated in 2008, 2013, and 2024, aimed to reduce heat loss in buildings, ensure energy savings, and regulate the procedures and principles related to implementation (TS 825, 2024).

Traditional thermal insulation materials that can be used in building envelopes are divided into two main categories: inorganic-based (expanded perlite and vermiculite, glass foam, glass wool, rock wool) and organic-based (hemp, wood fiber and chipboards, cork products, cellulosic fibers, extruded polystyrene, expanded polystyrene, polyurethane, phenolic foams). However, there is a high input of raw materials and significant energy consumption involved in the high-temperature production process. Additionally, environmental issues arise due to waste emissions into the air, soil, and water during the production of these materials. In recent times, there has been an intensified search for environmentally friendly, sustainable, and economical thermal insulation materials to solve these issues. Waste-based thermal insulation materials produced from various inorganic and organic wastes may be considered a sustainable alternative to traditional thermal insulation materials. Therefore, the aim of this research is to evaluate the potential use of "waste-based thermal insulation materials" produced from various wastes in the literature as an alternative to traditional thermal insulation materials in building envelopes for five different climate regions in Türkiye, as determined by the TS 825 Standard. In this context, the optimal location and thickness of waste-based thermal insulation materials in the external wall section, consisting of different layers, have been determined for each climate region of Türkiye, using simulation methods.

2. Methodology

2.1. Simulation data

The Izoder TS 825 Calculation Program was used to simulate the thermal performance of the building envelope according to the climatic conditions of Türkiye. The building function was chosen as “residential,” and the wall type as “exterior wall exposed to outdoor climate conditions”. The thermal transmittance coefficient, known as the “U_{wall} value (U-value),” of wall sections composed of various layers was calculated using the program. According to the TS 825, this value represents the amount of heat transmitted per unit time from a surface area of 1 m^2 with a temperature difference of 1 Kelvin, and its unit is W/m^2K. The U-value is calculated by considering the sum of the thermal resistances (R) of all the layers in the building envelope, and is expressed by Equation 1:

$$U - value = \frac{1}{\text{Rtotal}} = \frac{1}{\text{Rsi} + \sum_{i=1}^{n}\left(\frac{di}{\lambda\text{i}}\right) + Rse} \qquad (1)$$

- Rsi and Rse are the thermal resistances of the inner and outer surfaces, respectively ($m^2 \cdot K/W$),
- di is the thickness of each layer (m),
- λi is the thermal conductivity coefficient of each layer (W/mK),
- $\sum_{i=1}^{n}\left(\frac{di}{\lambda\text{i}}\right)$ is the total thermal resistance of the layers that create the wall,
- n is the number of layers in the wall.

The U-values that building envelope components should have according to climate regions in TS 825 are provided in Table 1.

Table 1. U-values for climate regions of Türkiye (TS 825, 2024)

Climate region	U_{wall}	U_{window}
1st region	0.7	2.4
2nd region	0.6	
3rd region	0.5	
4th region	0.4	
5th region	0.4	

The calculated U-value was compared with the limit values, specified for the relevant region in the TS 825 standard (Table 1). The inspection of condensation was carried out in the section that only met the U-value requirement. In the program database, the situation where the vapor diffusion curve and the saturation pressure curve determined according to the temperature distribution in the wall section do not intersect in any month is defined as the "ideal situation" in terms of condensation. Condensation occurs when two curves intersect in any month.

2.2. Simulated wall sections and materials

The wall type (single-layered or cavity wall), wall materials, the thickness, hygrothermal properties, and their location affect the thermal performance of the building envelope. Therefore, in this research, simulations were conducted by designing various wall compositions as follows:

- Wall insulated from the outside (Figure 1a)
- Wall insulated from the inside (Figure 1b)
- Wall insulated from the outside and inside (Figure 1c)

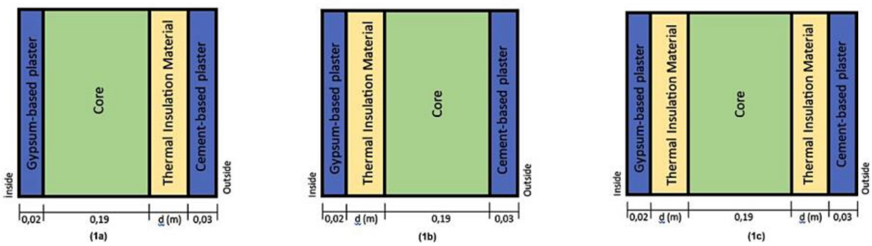

Figure 1. Simulated wall sections: (1a) wall insulated from the outside; (1b) wall insulated from the inside; (1c) wall insulated from the outside and inside.

The properties of the selected materials are provided in Table 2.

Table 2. The properties of the selected materials.

Material				Unit weight (kg/m³)	Thermal conduct. (W/mK)	Vapor diff. resist. factor (μ)
Core	FCB	Vertically perforated		1400	0.58	5
Core	AAC	With special adhesive		600	0.19	5
Rendering	Gypsum-based plaster			1400	0.70	10
Rendering	Cement-based plaster			2000	1.60	15
Thermal Insulation	Glass wool		Traditional	8-500	0.040	1
Thermal Insulation	Waste glass (Ayadi et al., 2011)		Waste-based	> 500	0.031	-
Thermal Insulation	Feldspathic waste (Kazmina et al., 2016)			-	0.083	-
Thermal Insulation	Waste olive seeds, ground PVC and wood chips (Binici and Aksogan, 2016)	Gypsum binder		1280-1330	0.096	-

	Corn cob (Binici et al., 2015)	Gypsum +cement binder		500-800	0.10	-
	Date palm fibers (Chikhi et al., 2013)	Gypsum binder		753	0.15	-
	Sunflower stalk and textile waste (Binici et al., 2014)	Gypsum binder		720	0.16	-
	Straw (Reif et al., 2016)			95-120	0.047	4
	Textile fibre waste (Barbero-Barrera et al., 2016)	Hydraulic lime		716-1013	0.14-0.21	-
	Coconut husk (Panyakaew and Fotios, 2011)			250-350	0.046-0.068	-
	Sugarcane bagasse (Panyakaew and Fotios, 2011)			250-350	0.049-0.055	-
	Cotton stalk fibers (Zhou et al., 2010)			150-450	0.058	-
	Onion skin, peanut shell fibres, perlite, cement (Binici and Aksogan, 2017)			1330	0.062	-

Vertically perforated fired clay bricks (FCB) (in accordance with TS EN 771-1+A1, 2015) or aerated autoclaved concrete blocks (AAC) (in accordance with TS EN 771-4+A1, 2015) with a thickness of 19 cm were used to produce the core of the wall. Gypsum-based plaster having 2 cm and cement-based plaster having 3 cm were selected as interior and exterior renderings, respectively. In order to examine the effectiveness of WBTIs on the thermal performance, a wall section containing traditional glass wool (TS EN 13162+A1, 2015) with 5 cm thickness was defined as the "reference wall section."

The possibilities of producing a material similar to glass foam from waste glass were investigated experimentally. 1% $CaCO_3$ was added as a foaming agent to 99% glass powder to make the material porous. Then, it was pressed at 8% moisture and 850 °C. The thermal conductivity, unit weight, water absorption ratio, and compressive strength of the produced sample were 0.031 W/mK, 500 kg/m^3, 10% and 17.5 MPa, respectively (Ayadi et al., 2011). In another study, the possibility of using feldspathic waste generated during metal processing in the production of expanded glass thermal insulation materials was investigated. When producing expanded glass, waste glass was crushed and mixed with water to form a paste. Then, a foaming agent was added, and it was expanded at approximately 900 °C. During this process, excessive energy consumption occurred. Frit was produced from feldspathic wastes at lower temperatures (<900 °C), after which SO_3 was added as an expansion agent, causing the frit to expand. It was identified as an alternative to expanded glass thermal insulation material, which had a thermal conductivity coefficient of 0.083-0.087 W/mK, a unit weight of 330-380 kg/m^3, and a compressive strength of 2.8-3.5 MPa (Kazmina et al., 2016).

Olive seed waste, wood chip waste, waste PVC, along with gypsum used as a binder, were used to produce thermal insulation materials. Olive seed and wood chip wastes were ground and mixed in varying proportions. After being blended for 5 minutes, gypsum and water were added. After the mixture was poured into molds, it was pressed for 2 minutes. Samples were removed from the mold after 1 day, and dried in an oven at 110 °C for 2 days. The material had a thermal conductivity coefficient of 0.096-0.099 W/mK, a unit weight of 1280-1330 kg/m^3 and a compressive strength of 0.25-0.35 MPa (Binici and Aksogan, 2016). In research on the production possibilities of corn cob-based thermal insulation materials, ground corn cobs were mixed with varying ratios of cement and gypsum. Then, the material was made porous using NaOH, aluminum powder, and water. The thermal conductivity of the samples was between 0.10-0.19 W/mK; the unit weight was between 500-800 kg/m^3; and the water absorption ratio was between 12-24% (Binici et al., 2015).

In the study examining the production possibilities of thermal insulation materials using date palm fibers, the waste fibers were dried and ground, and then, various mixtures were prepared with gypsum. The physical and mechanical properties of the samples were determined after 14 and 28 days. In the produced samples, the thermal conductivity coefficient was between 0.15-0.17 W/mK; the unit weight was 753 kg/m^3 (Chikhi et al., 2013). In another research, the possibilities of producing thermal insulation materials using sunflower stalks and textile waste were also investigated. The material used gypsum as a binder. The raw materials were first ground, mixed in different proportions, then molded, and finally shaped under pressure. The produced samples had a thermal conductivity coefficient of 0.16 W/mK, a unit weight of 720 kg/m^3, and a water absorption ratio of 71% (Binici et al., 2014). In another study evaluating the production possibilities of thermal insulation materials using straw, the obtained values for the thermal conductivity coefficient (0.047 W/mK), unit weight (95-120 kg/m^3), and water vapor diffusion resistance factor (4) were promising (Reif et al., 2016).

The thermal insulation material, produced using textile fiber waste and hydraulic lime binder, and dried in an oven at 40 °C for 15 days, had a thermal conductivity of 0.14-0.21 W/mK, a unit weight of 716-1013 kg/m^3, and a compressive strength of 3.22-7.62 MPa (Barbero-Barrera et al., 2016). Thermal insulation materials were produced using wastes from coconut fiber production and sugarcane production. The thermal conductivity coefficients of the materials were 0.046-0.068 W/mK and 0.049-0.055 W/mK, respectively, and the unit weights ranged from 250-350 kg/m^3 (Panyakaew and Fotios, 2011). In another study, the production possibilities of thermal insulation boards from waste cotton stalk fibers were investigated. Cotton stalks were cut into sizes of 25x10x5 mm, soaked in water, and then softened with pressurized steam. Then, they were turned into fibers and dried in an oven at 100 °C. The fibers were compressed under various densities and pressures to form boards. The produced samples had a thermal conductivity coefficient of 0.058 W/mK, and a unit weight of 150-450 kg/m^3 (Zhou et al., 2010). Onion skin and peanut shell fibers were ground and mixed with perlite and cement, resulting in a thermal insulation material with a thermal conductivity coefficient of 0.062 W/mK and a unit weight of 1330 kg/m^3 (Binici and Aksogan, 2017).

2.3. Climatic conditions

According to TS 825, different climatic characteristics are observed in five climate regions in Türkiye. The 1st-degree climate region exhibits hot-humid climate characteristics, with Antalya the representative province. Istanbul, representing the 2nd-degree climate region with a temperate-humid climate, has been chosen. Temperate-dry climate characteristics prevail in Ankara, which is located in the 3rd-degree climate region. The representative cities of the climate regions of the 4th- and 5th-degrees, which have, respectively, hot-dry and cold climate characteristics, are Van and Erzurum.

The annual average temperature in Antalya is 18.9 °C. In January, the lowest temperature is recorded at 6.1°C, while in July, the highest temperature is recorded at 34.2 °C (Url-1). The annual average temperature in Istanbul and Ankara is measured at 15.3 °C and 12.0 °C, respectively. In January and February, the lowest temperatures are recorded at 4.2 °C in Istanbul and -3.1 °C in Ankara, whereas the highest temperatures are recorded at 29.7 °C in Istanbul and 30.5 °C in Ankara in August (Url-2, Url-3). In Van, located in the fourth-degree climate region, the annual average temperature is 9.5 °C. In January, the lowest temperature of the year is recorded at -7.5 °C, while in August, the highest temperature is recorded at 28.5 °C (Url-4). In Erzurum, which is the coldest climatic region, the annual average temperature is measured as 5.8 °C. The lowest temperature of the year is recorded at -13.9 °C in January, while the highest temperature is recorded at 27.3 °C in August (Url-5).

3. Result and Discussion

3.1. First-degree climate region

Figure 2 shows the U-values provided by WBTI of different locations and thicknesses, for wall sections with FCB or AAC cores in Antalya.

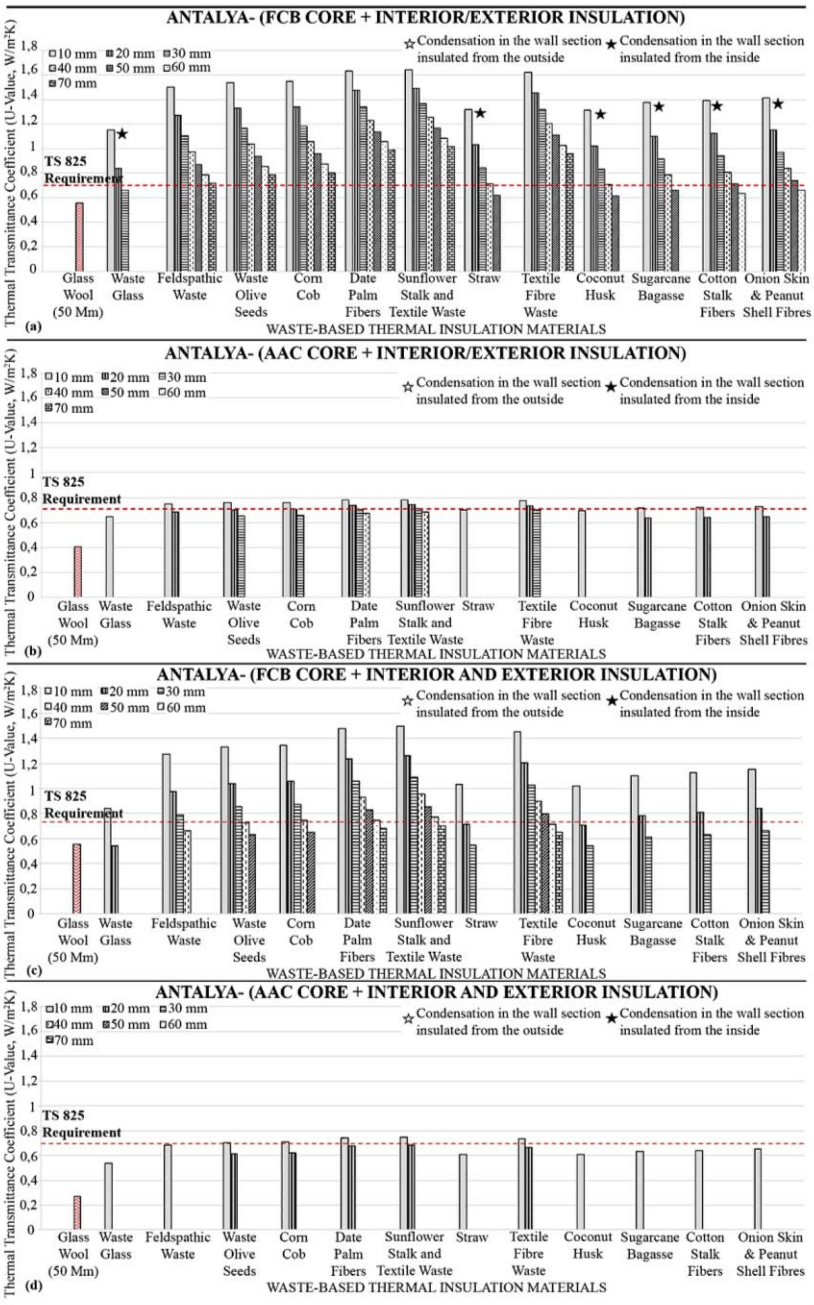

Figure 2. U-values provided by WBTI for different locations and thicknesses in Antalya: (a) FCB core with interior or exterior insulation; (b) AAC core with interior or exterior insulation; (c) FCB core with interior and exterior insulation; (d) AAC core with interior and exterior insulation.

The reference wall section with an FCB core and 50 mm glass wool insulation has a U-value of 0.55 W/m^{2}K, meeting the TS 825 requirement (Figure 2a). When WBTI was used in the interior or exterior region of the wall instead of traditional glass wool, the TS 825 requirement could be met with 30 mm waste glass, 50 mm straw, sugarcane bagasse, and coconut husk and 60 mm cotton stalk fibers and onion skin and peanut shell fibers. On the other hand, feldspathic waste, waste olive seeds, corn cob, date palm fibers, sunflower stalk and textile waste, and textile fiber waste were insufficient to meet the U-value of the FCB-based wall. Placement of the WBTI in the interior or exterior region of the wall section did not change the U-value. However, according to Figure 2a, WBTIs placed in the exterior region of the wall did not allow condensation in any month of the year, while waste glass, straw, coconut husk, sugarcane bagasse, cotton stalk fibers, and onion skin and peanut shell fibers placed in the interior region led to condensation.

The location of WBTI within the building envelope affects the hygrothermal properties of the building envelope and consequently its thermal performance. The WBTI, which was placed in the exterior region, kept the surface of the wall materials close to the indoor temperature, minimizing temperature fluctuations and thus, the formation of thermal stresses on the materials, reducing the total heat loss of the building envelope and consequently the total heating/cooling energy consumption of the building. When WBTI was placed in the interior region, the core material (FCB or AAC) had a hot surface in the summer and a cold surface in the winter, and it was subjected to thermal stresses due to the temperature difference between day and night in the external environment. In the Fourier heat conduction law, which is one of the fundamental laws of heat transfer, the direction of heat transfer is from the environment with a higher temperature to the one with a lower temperature (Narasimhan, 1999). Similarly, according to Fick's law, the direction of water vapor transfer is from the environment with a higher partial pressure to the one with a lower partial pressure (Thorstenson and Pollock, 1989). Especially in the winter months, when the warm indoor air and the increased water vapor pass through the building envelope to the outside, the vapor condenses into a liquid if it encounters a temperature below its dew point. This phenomenon, referred to as condensation, can occur in any area of the wall section. As a result of condensation, the pores of the WBTI fill with water, increasing the thermal conductivity coefficient and causing the material to lose its thermal insulation properties. Additionally, as a result of condensation, mold formation occurs in the wall section, posing a risk to user health (Toydemir et al., 2000). Therefore, in this study, the risk of condensation developing in the FCB-based wall with interior insulation should be considered.

When the AAC core with the same thickness was used instead of FCB (Figure 2b), all WBTIs used in the interior or exterior regions met the TS 825 requirement. Additionally, the thicknesses of these materials were reduced compared to FCB-based walls. For example, an AAC-based wall, either internally or externally insulated, achieved the U-value using various WBTIs with different thicknesses: 10 mm waste glass, straw, and coconut husk; 20 mm feldspathic waste, sugarcane bagasse, cotton stalk fibers, and onion skin and peanut shell fibers; 30 mm waste olive seeds, corn cob, and textile fiber waste; 40 mm date palm fibers and sunflower stalk and textile waste. Condensation detected in the FCB-based walls did not occur in the AAC-based walls. This situation was due to the internal structure of AAC having a greater void ratio (porosity) compared to FCB of the same thickness, and therefore a lower vapor diffusion resistance factor. Higher porosity and lower vapor diffusion resistance facilitate the transition of water vapor, denser indoors to the external environment, especially during the winter months, and prevent condensation of vapor in any part of the wall section. However, in the first-degree climate region, the winter months are relatively milder compared to other regions. As the temperature difference between the interior and exterior environments increases, the risk of condensation in the wall section also rises.

The U-values obtained from placing WBTIs on both the interior and exterior regions of the FCB-based wall are shown in Figure 2c. Only sunflower stalk and textile waste-based materials were insufficient to achieve the desired U-value. That is, materials placed only in the interior or exterior region, which were insufficient to meet the U-value, achieved the U-value through the application of internal and external insulation. Additionally, the thicknesses of the WBTIs to be used in the interior and exterior insulation applications were reduced compared to other sections. For example, 20 mm waste glass; 30 mm straw, coconut husk, sugarcane bagasse, cotton stalk fibers, and onion skin and peanut shell fibers; 40 mm feldspathic waste; 50 mm waste olive seeds and corn cob; 70 mm date palm fibers and textile fiber waste could meet the specified requirements without condensation. When the AAC core of the same thickness was used instead of FCB (Figure 2d), all WBTIs were sufficient to meet the U-value without condensation, even when reduced to 10- or 20-mm thicknesses.

3.2. Second-degree climate region

Figure 3 shows the U-values provided by WBTI of different locations and thicknesses, for wall sections with FCB or AAC cores in Istanbul. The reference wall section with an FCB core and 50 mm glass wool insulation has a U-value of 0.55 W/m^{2}K, meeting the TS 825 requirement (Figure 3a). When WBTI was used in the interior or exterior region of the wall instead of traditional glass wool, the TS 825 requirement could be met with 40 mm waste glass, 60 mm straw and coconut husk, 70 mm sugarcane bagasse, cotton stalk fibers and onion skin and peanut shell fibres. On the other hand, feldspathic waste, waste olive seeds, corn cob, date palm fibers, sunflower stalk and textile waste, and textile fiber waste were insufficient in meeting the U-value of the FCB-based wall. Placement of the WBTI in the interior or exterior region of the wall section did not change the U-value. However, according to Figure 3a, all WBTIs that met the U-value led to condensation when placed in either the interior or exterior region of the wall.

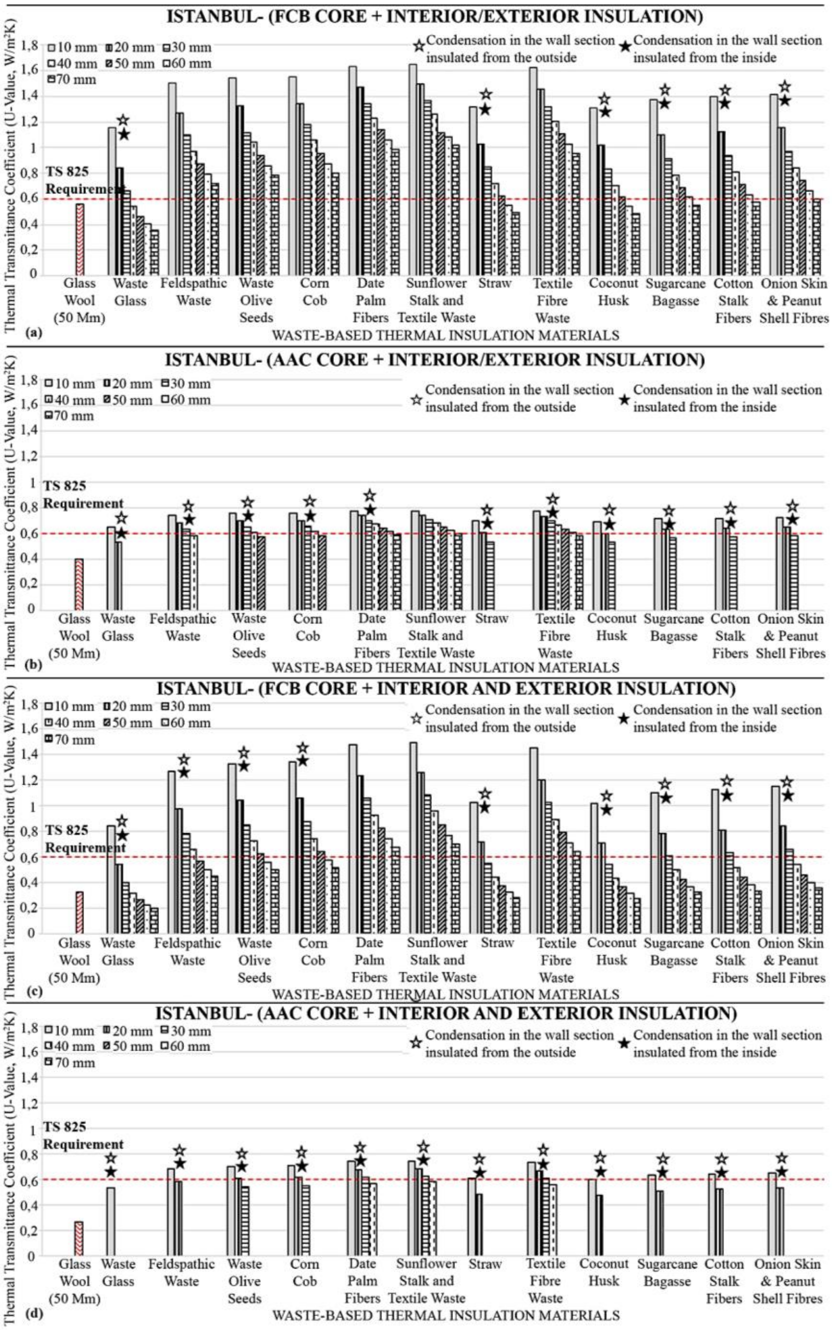

Figure 3. U-values provided by WBTI for different locations and thicknesses in İstanbul: (a) FCB core with interior or exterior insulation; (b) AAC core with interior or exterior insulation; (c) FCB core with interior and exterior insulation; (d) AAC core with interior and exterior insulation.

When the AAC core with the same thickness was used instead of FCB (Figure 3b), all WBTIs except for sunflower stalk and textile waste met the TS 825 requirement. Additionally, the thicknesses of these materials were also reduced compared to FCB-based walls. For instance, an AAC-based wall either internally or externally insulated achieved the required U-value using 20 mm waste glass; 30 mm straw, coconut husk, sugarcane bagasse, cotton stalk fibers and onion skin and peanut shell fibres; 40 mm feldspathic waste; 50 mm waste olive seeds, and corn cob; 70 mm date palm fibers and textile fibre waste. However, despite the use of AAC in these wall sections, condensation formation could not be prevented during the winter months. Although there was no risk of condensation in AAC-based wall sections in Antalya, a risk of condensation was detected in Istanbul due to the differences in the climates of the regions. Especially in winter, the lower outdoor temperature in Istanbul increased the temperature difference between the indoor and outdoor environments. Therefore, during the vapor transition from the indoor environment to the outdoor environment, when water vapor encountered a temperature below its dew point, it condensed and became liquid.

The U-values obtained from placing WBTIs on both the interior and exterior regions of the FCB-based wall are shown in Figure 3c. Sunflower stalk and textile waste, date palm fibers, and textile fiber waste-based WBTIs were insufficient in achieving the U-value. In addition, all other WBTIs used were able to achieve the U-value with thinner sections compared to the others. When AAC core with the same thickness was used instead of FCB (Figure 3d), the thicknesses of all WBTIs were successfully reduced to 10-30 mm, achieving the desired U-value.

3.2. Third-degree climate region

Figure 4 shows the U-values provided by WBTI of different locations and thicknesses, for wall sections with FCB or AAC cores in Ankara. When WBTI was used in the interior or exterior region of an FCB-based wall, the TS 825 requirement could only be met with 40 mm waste glass, 60 mm straw, and coconut husk. Other WBTIs were insufficient in meeting the required U-value under the climatic conditions of Ankara. As seen in Figure 4a, WBTIs that meet the U-value, were not successful in preventing condensation risk on the wall when used in either the interior or exterior regions. According to Figure 4b, in the case of using AAC in the wall core, in addition to waste glass (20 mm), straw (40 mm), and coconut husk (40 mm), feldspathic waste (40 mm), sugarcane bagasse (50 mm), cotton stalk fibers (50 mm), and onion skin and peanut shell fibers (50 mm) were also able to meet the required value. However, it was determined that further precautions need to be taken in AAC-based wall sections to prevent condensation in the climatic conditions of Ankara.

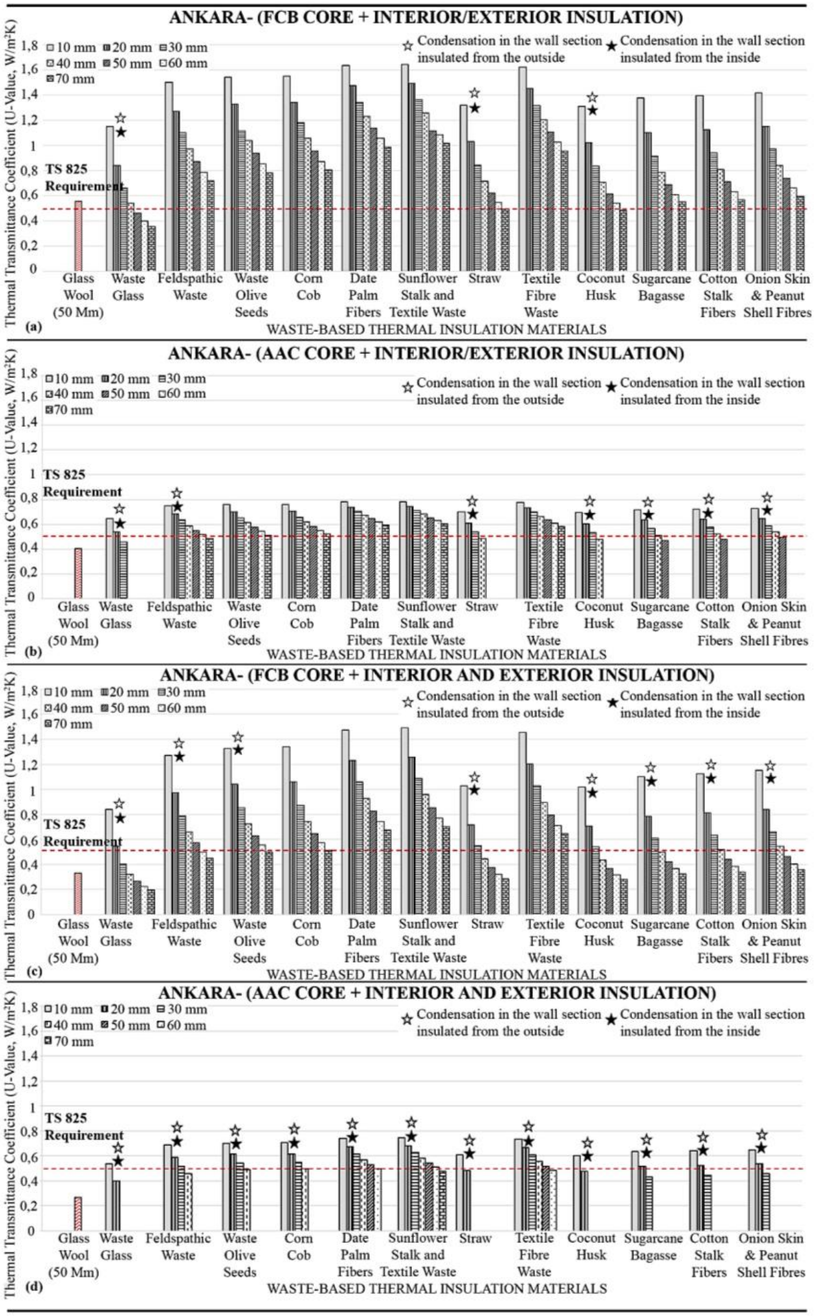

Figure 4. U-values provided by WBTI for different locations and thicknesses in Ankara: (a) FCB core with interior or exterior insulation; (b) AAC core with interior or exterior insulation; (c) FCB core with interior and exterior insulation; (d) AAC core with interior and exterior insulation.

The U-values obtained from placing WBTIs on both the interior and exterior regions of the FCB-based wall are shown in Figure 4c. Date palm fibers, sunflower stalk and textile waste, coconut husk, and textile fiber waste-based thermal insulation materials were not adequate to achieve the U-value. The thickness of the waste glass, and straw decreased to 20 mm, and 30 mm, respectively, when applied as double-layers compared to the single-layer WBTI integrated wall section. The feldspathic waste (60 mm), waste olive seeds (60 mm), corn cob (70 mm), sugarcane bagasse (40 mm), cotton stalk fibers (40 mm), and onion skin and peanut shell fibers (40 mm) when integrated into the interior and exterior regions of the wall could meet the U-values in the third-degree climate zone. In the wall section with a double-layered WBTI, integrated with an AAC core, all WBTIs included in the study could meet the TS 825 requirements within the thickness range of 10-60 mm.

3.3. Fourth-degree climate region

Figure 5 shows the U-values provided by WBTI of different locations and thicknesses, for wall sections with FCB or AAC cores in Van. When WBTI was used in the interior or exterior region of a wall with an FCB core, the TS 825 requirement, could only be met with 70 mm waste glass, but additional measures needed to be taken to prevent the risk of condensation. Other WBTIs were insufficient in meeting the U-value under the climatic conditions of Van. According to Figure 5b, in the case of using AAC as a core material, waste glass (40 mm), straw (70 mm), and coconut husk (60 mm) were able to meet the U-value.

The U-values obtained from placing WBTIs on both the interior and exterior regions of the FCB-based wall are shown in Figure 5c. In the mentioned section, waste glass (30 mm), straw (50 mm), coconut husk (50 mm), sugarcane bagasse (60 mm), cotton stalk fibers (60 mm), and onion skin and peanut shell fibers (70 mm) could be used as thermal insulation materials. When using AAC instead of FCB (Figure 5d), all materials except date palm fibers, sunflower stalk and textile waste, and textile fiber waste were suitable for use in Van.

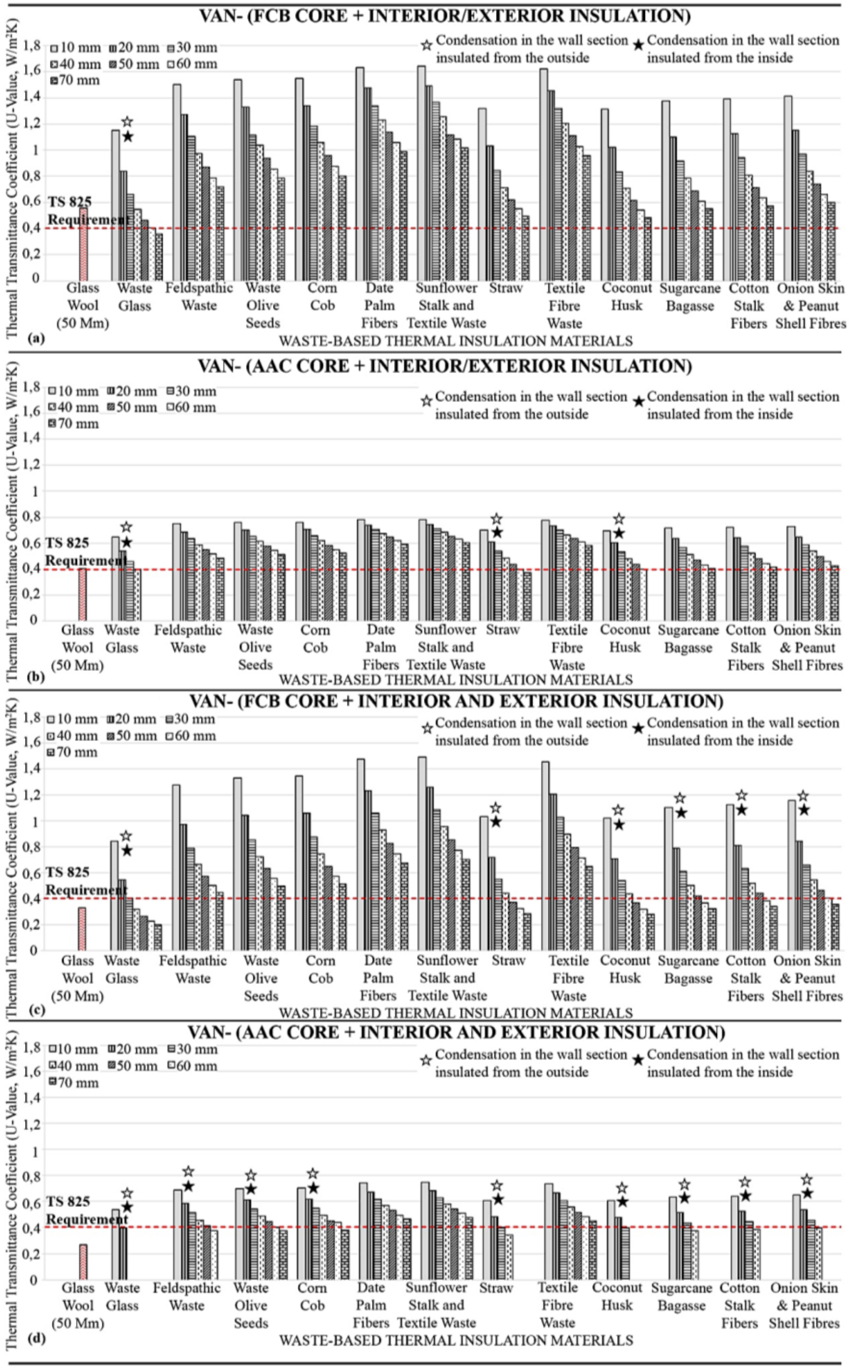

Figure 5. U-values provided by WBTI for different locations and thicknesses in Van: (a) FCB core with interior or exterior insulation; (b) AAC core with interior or exterior insulation; (c) FCB core with interior and exterior insulation; (d) AAC core with interior and exterior insulation.

3.4. Fifth-degree climate region

Figure 6 shows the U-values provided by WBTI of different locations and thicknesses, for wall sections with FCB or AAC cores in Erzurum. When WBTI was used in the interior or exterior region of the FCB-based wall, the TS 825 requirement could only be met with 70 mm waste glass. In the aforementioned section, there was a risk of condensation. According to Figure 6b, in the AAC-based wall section, as in the fourth-degree climate zone, waste glass (40 mm), straw (70 mm), and coconut husk (60 mm) met the requirement.

By placing WBTIs on both the interior and exterior regions with an FCB core (Figure 6c), waste glass (40 mm), straw (50 mm), coconut husk (50 mm), sugarcane bagasse (60 mm), cotton stalk fibers (60 mm), and onion skin and peanut shell fibers (70 mm) could be used as thermal insulation materials. As for AAC core (Figure 6d), all materials except date palm fibers, sunflower stalk and textile waste, and textile fiber waste met the required value.

The comparison of the usability of WBTI types in wall sections that comply with TS 825 requirement, in various climate regions, is provided in Table 2. Accordingly, the WBTIs suitable for use in all climate regions are waste glass and straw, followed by coconut husk. Sugarcane bagasse, cotton stalk fibers, and onion skin and peanut shell fibers, while providing usage possibilities in the first, second, and third-degree climate zones, can meet U-value requirements when used in both the interior and exterior of walls in the fourth and fifth-degree climate zones. Similarly, feldspathic waste, waste olive seeds, and corn cob offer more usage possibilities in the first and second-degree climate regions. However, date palm fibers, textile fiber waste, and sunflower stalk and textile waste are WBTI materials that cannot be used in third-, fourth-, and fifth-degree climate zones. In other words, as the country's climate progresses from hot/mild climate characteristics to cold and continental climates, the types of WBTI that can meet TS 825 requirements decrease. Additionally, as one shifts towards a colder and continental climate, the thickness or the number of layers of WBTI that can provide the same U-value needs to be gradually increased. It is not correct to make use of only one standard thermal insulation system, for the building envelope in our country, which experiences all four seasons. In this case, to determine the most suitable combination of materials and layering type for each climate zone, the system should be considered as a whole, based on the existing conditions. Additionally, evaluations should consider other criteria such as condensation, health effects, in addition to thermal performance.

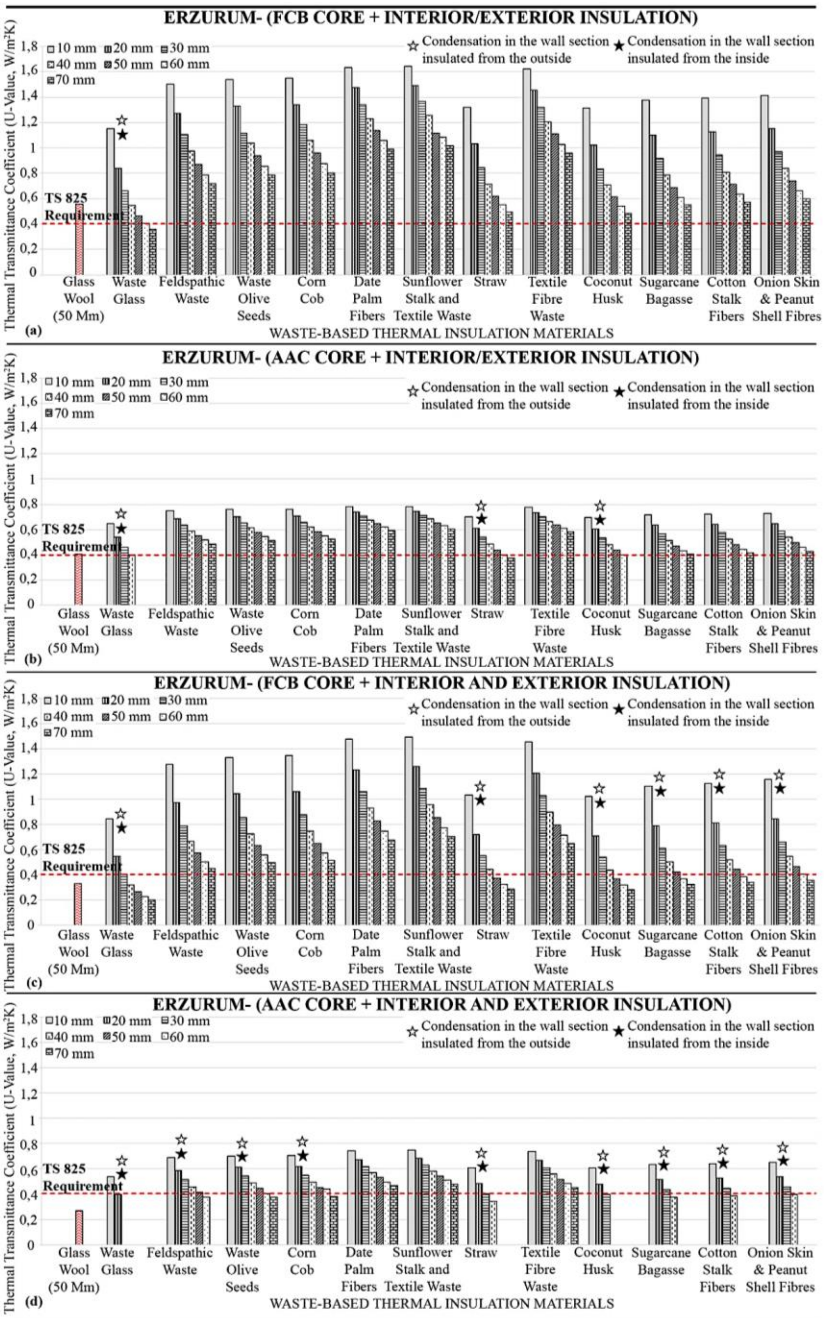

Figure 6. U-values provided by WBTI for different locations and thicknesses in Erzurum: (a) FCB core with interior or exterior insulation; (b) AAC core with interior or exterior insulation; (c) FCB core with interior and exterior insulation; (d) AAC core with interior and exterior insulation.

When the findings obtained in this research were analyzed, it was determined that WBTIs of different thicknesses successfully met the TS 825 standard requirements. In building materials/elements, the movement of vapor flow is from high pressure to low pressure, similar to heat flow. Although the transfer of vapor through building elements is beneficial, especially in thermal insulation materials, the condensation can create challenging problems (Toydemir et al., 2000). The absence of condensation in the first-degree climate region demonstrates that these materials can be safely used in wall sections. To prevent the condensation risk detected in other climate regions, it is suggested to either prevent the vapor condensation within the thermal insulation material or use closed-cellular, water- and vapor-impermeable thermal insulation materials. However, since the WBTIs evaluated in this study are open-cellular materials, it is recommended to use a vapor barrier in the wall section to prevent the risk of condensation.

The most commonly used materials as vapor barriers are bituminous sheets, PVC sheets, and plastic copolymers sheets. When these sheets are reinforced with aluminum or copper foils, their impermeability properties are further enhanced (Toydemir et al., 2000). As a result of using these vapor barriers in wall sections that have condensation risk in the current study, it will be possible to use WBTIs without allowing condensation.

When determining the type and location of the vapor barriers to be used in the building envelope, parameters such as climatic conditions, including ambient temperature and relative humidity, should be taken into account. In cold climates, water vapor tends to move from the warmer and more humid interior part of the building envelope to the colder and drier exterior environment. Therefore, the vapor barrier should be placed on the warmer side of the thermal insulation material facing the interior. In hot and humid climates, vapor tends to move from the warmer and more humid outside environment to the cooler and drier interior. Therefore, the vapor barrier should be placed on the cold side of the insulation layer facing the outside environment (Al-Homoud, 2005).

Table 2. Comparison of WBTI usage possibilities in wall sections meeting TS 825 requirements in various climate regions.

Climatic region	Wall section	Waste glass	Feldspathic waste	Waste olive seeds	Corn cob	Date palm fibers	Sunflower stalk& textile	Straw	Textile fibre waste	Coconut husk	Sugarcane bagasse	Cotton stalk fibers	Onion skin & peanut shell fibres
Antalya	FCB-interior/exterior ins.	◊						◊			◊	◊	◊
	FCB-interior and exterior ins.	◊	◊	◊	◊	◊		◊	◊	◊	◊	◊	◊
	AAC-interior/exterior ins.	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦
	AAC-interior and exterior ins.	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦
İstanbul	FCB-interior/exterior ins.	◊						◊		◊	◊	◊	◊
	FCB-interior and exterior ins.	◊	◊	◊	◊			◊		◊	◊	◊	◊
	AAC-interior/exterior ins.	♦	♦	♦	♦	♦		♦	♦	♦	♦	♦	♦
	AAC-interior and exterior ins.	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦
Ankara	FCB-interior/exterior ins.	◊						◊		◊			
	FCB-interior and exterior ins.	◊	◊	◊	◊			◊		◊	◊	◊	◊
	AAC-interior/exterior ins.	♦	♦					♦		♦	♦	♦	♦
	AAC-interior and exterior ins.	♦	♦	♦	♦			♦		♦	♦	♦	♦
Van	FCB-interior/exterior ins.	◊											
	FCB-interior and exterior ins.	◊						◊		◊	◊	◊	◊
	AAC-interior/exterior ins.	♦						♦		♦			
	AAC-interior and exterior ins.	♦	♦	♦	♦			♦		♦	♦	♦	♦
Erzurum	FCB-interior/exterior ins.	◊											
	FCB-interior and exterior ins.	◊						◊		◊	◊	◊	◊

	AAC-interior/exterior ins.	♦						♦		♦			
	AAC-interior and exterior ins.	♦	♦	♦	♦			♦		♦	♦	♦	♦
Total wall section		**20**	**11**	**10**	**10**	**5**	**3**	**18**	**5**	**17**	**15**	**15**	**15**

4. Conclusion

The outcomes of the findings obtained from this research can be summarized as follows:

- WBTIs produced using different manufacturing methods exhibit successful performance in meeting the U-value requirement of the TS 825 under various climate conditions in Türkiye.
- Although waste glass and straw meet U-value requirements in provinces representing all climate regions, sugarcane bagasse, cotton stalk fibers, onion skin and peanut shell fibers, feldspathic waste, waste olive seeds, and corn cob are materials with more limited use in continental climate conditions. However, these materials can be used in the relevant climates when suitable precautions are taken to prevent the risk of condensation. On the other hand, date palm fibers, textile fiber waste, and sunflower stalk and textile waste are not suitable for use in the third-, fourth-, and fifth-degree climate regions.
- In Türkiye, which has a diverse climate, it is not appropriate to apply the same wall section in the design of the building envelope. The appropriate layering and WBTI selection should be made by considering the characteristics of every climate region and evaluating the system as a whole.
- WBTI thickness varies according to different climate regions and wall sections. The thickness or number of layers of WBTI that can meet the U-value requirements increases from warm or temperate climates, to cold and continental climates.
- The vapor diffusion of WBTI must be completely in line with the building envelope. The movement of vapor through the wall section should allow the movement of vapor easily. If this is not possible, vapor barriers should be applied on surfaces where the vapor pressure is high.
- Both thermal performances, the risk of condensation that may occur in the building envelope, and the negative effects of condensation on indoor thermal comfort and health of the users should be taken into consideration.

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