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Cost analysis and feasibility of green building adaptation in low-rise residential housing: Evidence from Türkiye

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Abstract

This study evaluates the cost implications of green building practices in low-rise residential housing by analyzing three sample houses in Kayseri, Türkiye. It compares traditional construction systems with green alternatives, focusing on water efficiency, energy-saving technologies, and sustainable materials. The findings reveal that green buildings incur higher upfront costs, particularly due to photovoltaic systems and certified materials. However, when compared with traditional structures, they demonstrate clear long-term benefits in energy savings, environmental performance, and operational efficiency. Water-related costs were mainly driven by sanitary fixtures and appliances, while insulation dominated material expenses. By offering a localized cost comparison between traditional and green construction, this study fills a gap in the national literature and highlights the feasibility of sustainable housing in Türkiye. These insights aim to inform both policy development and practical applications, providing a valuable foundation for integrating green certification systems into future low-rise residential projects.

Keywords: green buildings, construction cost analysis, energy efficiency, b.e.s.t-residential certification, Türkiye, low-rise residential buildings

1. Introduction

Industrial and technological advances, while providing significant benefits, have also led to major environmental challenges such as climate change, ecological degradation, and pandemics (İmert, 2017; Zengin & Yamaçlı, 2023). In response, global and local initiatives, from international agreements to municipal regulations, have been developed to restore ecological balance.

The construction industry is a major contributor to carbon emissions across material production, construction, and operation phases, accounting for 34% of global energy consumption and 37% of total emissions (UNEP, 2022). The sector also relies heavily on cement and steel (Wang & Zhang, 2008). Due to its environmental impact, the sector faces increasing pressure to adopt sustainable practices. In this context, green buildings have become a key solution (Hwang et al., 2017; UNEP, 2022; USEPA, 2016).

Green buildings, often defined as high-performance or sustainable buildings, lack a universally agreed-upon definition. The EPA defines them as resource-efficient structures operating across their life cycle (Circo, 2007; Dania et al., 2013; Kibert, 2007; Olubunmi et al., 2016; USEPA, 2016; Yudelson, 2007). ASTM emphasizes performance standards, minimized environmental harm, and ecosystem support (ASTM, 2023). These buildings integrate environmental, economic, and social objectives and play a key role in the circular economy (Burnett, 2007).

Green buildings differ from traditional structures by prioritizing minimal resource use in design and operation (Guo et al., 2021; Hwang et al., 2017; Wedding, 2008; Zigenfus, 2008). They reduce environmental impact, improve worker productivity, lower absenteeism, and cut operational costs

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(Kats, 2003; Mozingo & Arens, 2014; Ries et al., 2006). Some studies report up to a 25% increase in productivity and significant reductions in water use and waste generation. However, some studies question energy efficiency claims; for example, 30% of LEED buildings may consume more energy than conventional ones (Newsham et al., 2009).

Recent studies indicate that although green buildings may involve higher initial costs, they provide long-term economic benefits by reducing operational and maintenance expenses (Dong, et al., 2025). In addition, the decreasing cost of renewable energy technologies, particularly photovoltaic (PV) systems, has improved the economic feasibility of green building applications (Wang et al., 2020). Recent research also highlights the importance of life-cycle assessment (LCA), considering both embodied carbon and operational energy in evaluating building sustainability (Taseer et al., 2025).

To assess sustainability performance, various green building rating systems have been developed worldwide. Türkiye has increased its interest in green buildings in response to both global pressures and local challenges (ÇŞB, 2020; Ramakrishnan et al., 2023) (Figure 1).

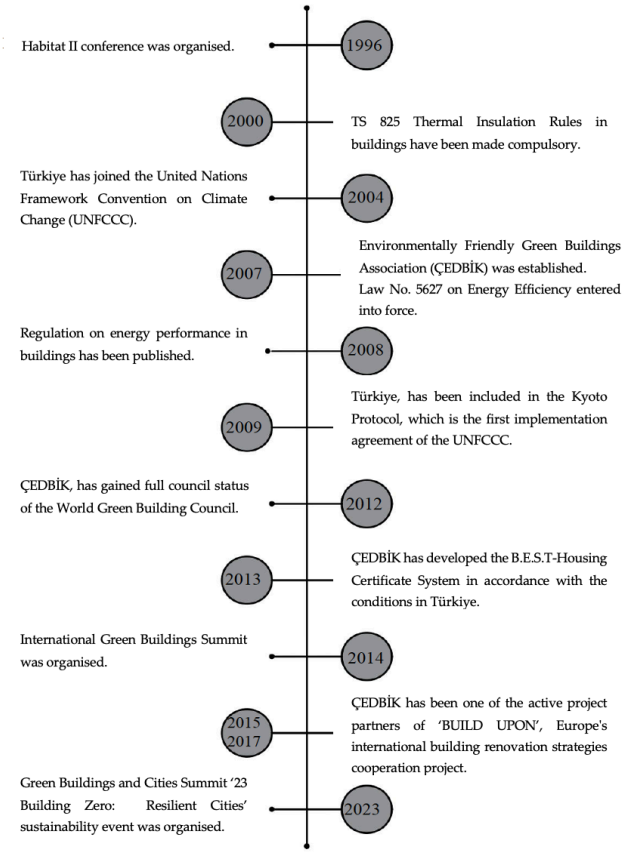

Figure 1 Historical development of green buildings in Türkiye

Rating systems provide sustainability benchmarks using data across design, construction, and operation stages (Ade & Rehm, 2019; Mateus & Bragança, 2011). These systems are adapted to local climatic, cultural, and regulatory conditions (Mattoni et al., 2018). Prominent global systems include BREEAM (UK), LEED (USA), CASBEE (Japan), and Green Star (Australia) (Portalatin et al., 2010) (Table 1).

Table 1 Green Building Certification Systems Worldwide

Certification System	Country	Certification System	Country
BREAM	England	HQE	France
IISBE	Canada	DGNB	Germany
SBTOOL	Canada	ESTIDAMA	United Arab Emirates

BEAT	Denmark	HK-BEAM	Hong-Kong
Protocollo Itaca	Italy	LEED-MEXICO	Mexico
GREEN STAR	Australia	TERI GRIHA	India
CASBEE	Japan	MINERGIE	Switzerland
NETHARLANDS	Netherlands	B.E.S.T	Türkiye

In Türkiye, institutions such as like the Ministry of Environment, universities, and NGOs have created local certification systems adapted from international models (Erdede & Bektaş, 2018). These systems evaluate design, construction, and operation phases and foster awareness among stakeholders (Table 2). Compared to European countries such as Austria, Germany, and Switzerland, where green building practices are widely implemented, Türkiye remains in a developing phase with increasing but limited adoption (Umaroğulları et al., 2020).

Table 2 Green Building Certification Systems Developed and Implemented in Türkiye

Year	Certification System	Institution
2008	Yeşil Yıldız (Green Star)	Ministry of Culture and Tourism
2013	B.E.S.T-Konut	ÇEDBİK
2013	Güvenli Yeşil Bina Belgesi	TSE
2014	SEEB-TR	YUAM
2019	YeS-TR	Ministry of Environment, Urbanisation and Climate Change

Kahramanmaraş and Hatay earthquakes (February 6, 2023) and the COVID-19 pandemic have further increased the demand for low-rise, resilient, and sustainable housing. In this context, understanding the economic feasibility of green building applications at the local scale is crucial for decision-makers, particularly in rapidly developing urban environments.

Recent studies have focused on the economic evaluation of photovoltaic systems and life-cycle cost analysis in residential buildings, highlighting the importance of energy price fluctuations and investment costs in determining economic feasibility (Wang et al., 2020; Taseer et al., 2025).

While previous studies have extensively examined green building practices at global and large scales, detailed, region-specific cost analyses for low-rise residential buildings remain limited in the Turkish context (Akgül et al., 2020; Bayat & Küçükali, 2022; Yalili Kılıç & Adalı, 2021).

Addressing this gap, the present study provides a localized, case-specific cost analysis in Türkiye, offering a more practical and implementable perspective for sustainable residential development. Specifically, this study examines how green building principles can be applied to low-rise residential buildings in Kayseri, contributing to both economic evaluation and resilience-oriented design approaches.

2. Materials and Methods

In this study, examples of low-rise residential buildings in Kayseri province were evaluated according to common characteristics of residential buildings with green certification both in Türkiye and worldwide, and in alignment with Türkiye's local certification criteria, namely the B.E.S.T-Residential (B.E.S.T-Konut) certificate. For each criterion, a cost analysis was conducted, and the resulting cost data were analyzed considering the hypothetical construction of these residential buildings according to green building standards.

Three residential buildings of varying total construction areas were selected to understand how these differences affect the implementation of green building practices and associated cost calculations. The first residential building has an area of 314.87 m², the second is 449.06 m², and the third is 439.3 m². The first residence was designed entirely independently from the second and third residences and has a smaller scale. Although the second and third residences have similar plan schemas and comparable are close, their facade openings differ depending on their scale. Investigating how these characteristics affect green building practices and the corresponding cost calculations was one of the reasons for selecting these specific residences.

2.1. Case Study Buildings Overview

The residences examined within this study are in two different residential complexes in the Çay Bağları area of Kayseri province and share standard floor plans. Buildings with approximately the same arrangement of floor plans were therefore selected for examination. Green building cost analyses were conducted for three different types of residential buildings.

The complex containing the first residence examined has four buildings. The ongoing construction status of the complex influenced its selection as a case study. It was assumed that green building implementations and cost analyses conducted on the sample building would serve as a reference to the contractor and encourage the application of similar practices. Furthermore, since the surrounding area of the site has a dense residential pattern, it is anticipated that the example could inspire nearby construction. The second and third detached residences are situated within the same site and have similar plan schemes.

These three buildings were examined, and green building practices and cost analyses were conducted. Residences of different sizes within the same site were specifically chosen to determine how size differences would impact construction costs under green building practices.

First building

The structure is positioned in the northeast direction within the plot, with its entrance located on the south facade. The building consists of three floors: basement, ground, and first floor (Figures 2, 3, 4). The basement floor contains a water tank, booster pump room, heating center, and corridor. The ground floor includes an entrance hall, living room-kitchen, a utility area, and a lavatory-WC; while on the first floor, there are showers, a hallway, laundry room, bathroom, dressing room, master bedroom, and children's bedrooms. Technical units are collected on the basement floor at elevation-3.30, while the ground floor at +0.20 elevation is designed for daily living areas. The first floor at +3.70 elevation has four bedrooms, each with a bathroom. Due to the anticipated extensive garden usage and climatic conditions, the building does not include balconies.

Figure 2 Basement floor (S-Line Mimarlık, 2022)

Figure 3 Ground floor (S-Line Mimarlık, 2022)

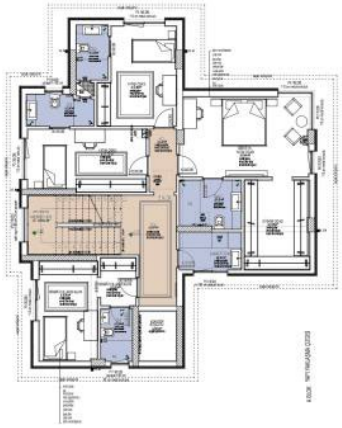

Figure 4 First floor (S-Line Mimarlık, 2022)

Since winters in Kayseri are cold, the building predominantly has large window openings facing south (Figure 5). The structural system is reinforced concrete, and the exterior facade consists of pumice blocks with rock wool insulation, plaster, and paint (Figure 6).

Figure 5 South facade (Author 1, 2024)

Figure 6 East facade (Author 1, 2024)

Second building

The building is oriented northeast to southwest, with the entrance situated on the southwest side. It is accessed through an elevation of 70 cm from ground level. The residence consists of three floors: a basement, a ground floor, and a first floor (Figures 7, 8, 9). The basement (-2.30 m level) contains predominantly storage areas, showers-WC, a boiler room, and a corridor. The ground floor (+0.70 m) includes a hallway, living room, sitting room, kitchen, WC, and terrace areas designed mainly for daily activities. The first floor, at +4.00 elevation, includes bedrooms, a dressing room, bathrooms, and a corridor.

Figure 7 B. floor (Toprak Tasarım Mimarlık, 2022)

Figure 8 G. floor (Toprak Tasarım Mimarlık, 2022)

Figure 9 First floor (Toprak Tasarım Mimarlık, 2022)

The residence has large window openings predominantly oriented to the northeast (Figure 10). Notably, the stairwell window opening enhances natural daylight within the interior spaces (Figure 11). Compared to the first residence, the window proportions are smaller. The structural system is reinforced concrete, and the exterior facade uses XPS insulation, plaster, and paint.

Figure 10 Northeast facade (Author 1, 2024)

Figure 11 East facade (Author 1, 2024)

Third building

The building is oriented in an east-west direction, with its entrance located on the west façade. It consists of three floors: the basement, the ground, and the first floor (Figures 12, 13, 14). The basement floor contains storage areas, a shower-WC, a boiler room, a hallway, and a pantry. The ground floor includes an entrance hall, living room, sitting room, kitchen, WC, and terrace designed primarily for daily living activities. It also includes extensive terrace areas. The first floor at +4.00 m elevation contains four bedrooms and bathrooms.

Figure 12 B. floor (Toprak Tasarım Mimarlık, 2022)

Figure 13 G. floor (Toprak Tasarım Mimarlık, 2022)

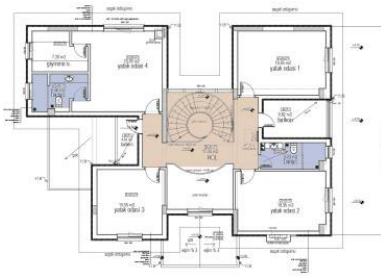

Figure 14 First floor (Toprak Tasarım Mimarlık, 2022)

The building has large window openings, predominantly on the southern façade (Figure 15), enhancing natural daylight intake. The window-to-wall ratio of this building is greater than that of the second building (Figure 16). The structure has a reinforced concrete system, with exterior finishes including XPS insulation, plaster, and paint.

Figure 15 Southern facade (Author 1, 2024)

Figure 16 East facade (Author 1, 2024)

2.2. Methodology

The residential projects in the Çay Bağları region of the Erenköy Neighborhood in Melikgazi District, Kayseri, were evaluated in accordance with Türkiye's local green building certification system, B.E.S.T-Residential. Residential building quality encompasses multiple performance dimensions, including energy efficiency, water conservation, material sustainability, acoustic comfort, and outdoor environmental conditions such as wind and noise control (ÇEDBİK, 2019; Kiraz, 2015). Within this broader framework, the present study focuses on three categories directly addressed by the B.E.S.T-Residential certification system: energy use, water use, and material use. According to the B.E.S.T-Residential certification system, points allocated for each category vary (Table 3).

Table 3 Scoring Table for B.E.S.T-Residential Certification According to Energy, Material, and Water Categories

Evaluation Criteria	Points Available	Design	Construction	Total
Renewable Energy Use	7	2	5	7
Energy Efficient White Goods	1		1	1
Use of Environmentally Friendly Materials	3		3	3
Reducing Water Use	1-6	4		4

According to the B.E.S.T-Residential certification, energy use can achieve up to seven points by utilizing renewable energy sources to reduce carbon emissions. In this study, solar energy was applied as a renewable energy source suitable for residential buildings. Conducting feasibility studies at the project stage awards 2 points, while the actual implementation of the technology awards 5 points. Furthermore, using energy-efficient appliances in homes contributes one additional point due to reduced carbon emissions (ÇEDBİK, 2019).

In the B.E.S.T-Residential certification, material usage is encouraged through the selection of environmentally labeled materials, based on life cycle analyses in construction. Accordingly, products with Environmental Product Declaration (EPD) labels were chosen for the exterior walls and facades of the studied buildings. Meeting these criteria under the B.E.S.T-Residential certification could earn three points (ÇEDBİK, 2019).

For water usage under the B.E.S.T-Residential certification, up to six points can be earned by implementing measures that save water both inside and outside residences. Measures outside residences, accounting for two points, were not considered in this study. Scoring for residential water usage varies between 1 and 4 points, depending on annual water consumption. Therefore, ensuring efficient water usage within residences could achieve up to four points (ÇEDBİK, 2019).

The 2024 (January) unit price lists from the Ministry of Environment, Urbanization, and Climate Change were primarily used. For items not included in this list, prices were obtained directly from relevant companies. Additionally, since certain green building components could only be specified by authorized companies, costs related to green building criteria were acquired from such firms. For instance, photovoltaic panel prices were included in the January 2024 unit price list by the Ministry of Environment, Urbanization and Climate Change. However, the characteristics of selected panels vary according to several factors, such as geographical location, roof area, and the operating time of heating devices in buildings. Therefore, an authorized company was consulted to determine the characteristics and costs of panels used in the buildings.

Based on calculations provided by Solimpeks, a solar thermal energy company operating in Türkiye (personal communication), the monthly electricity consumption was assumed to be 972 kWh for the first residential building and 1100 kWh for the second and third buildings. These assumptions formed the basis for the development of photovoltaic panel layout schemes for each building.

Cost evaluations included photovoltaic solar panels that convert solar energy into electrical energy and triple-glazed thermal insulation windows to minimize heat exchange. Private sector data were utilized to determine current prices and features of photovoltaic solar panels. For window selection, triple-glazed windows with low heat transfer values (U=0.90 W/m²K), providing high thermal insulation, were chosen, and data were sourced from the private sector. Additionally, the B.E.S.T-Residential certification encourages the use of energy-efficient appliances (A-class or higher) to reduce carbon emissions during operation, according to the certification manual.

Energy classes of appliances are indicated by letter notation representing energy efficiency, from A (highest efficiency) to G (lowest). Class A indicates good efficiency, A+ very good efficiency, and A++ high efficiency (Samsung, 2025). Because high-efficiency products are more costly, the most affordable A-class appliances meeting the required standards were chosen to minimize cost concerns. This approach was chosen to reflect realistic user preferences and cost considerations, while ensuring compliance with green certification requirements.

For material use, EPD-certified materials common among national and international green building certifications were targeted for use in construction. Accordingly, ISO 14025 Environmental Product Declarations (EPD)-certified materials were selected for external walls, including rock wool insulation, Probase Matik cement-based plaster, Probase mineral, and silicone-based exterior paints. Since these EPD-certified materials were not listed by the Ministry of Environment, Urbanization, and Climate Change, prices were collected from private sector companies. The total cost for these materials was calculated by multiplying the building's external wall area (g) by the unit price of the materials (h), as shown in Table 4 and Table 5.

Table 4 Calculation of the Quantity of the External Wall of the Building

Formula	Building Height (m)	Building Perimeter (m)	Deduction Quantity (m^2)	External Wall Quantity of the Building (m^2)
(d x e) - f = G	d	e	f	G

Table 5 Cost Calculation of Criteria for Material Utilization

Formula	External Wall Quantity of the Building (m^2)	Unit price (USD)	Total cost (USD)
g x h = M	g	h	M

Water-saving practices recommended by the B.E.S.T-Residential certification include selecting low-water-consuming fixtures, reservoirs, dishwashers, and washing machines, conforming to TS EN 200, TS EN 274, and TS EN 997 standards. Cost calculations were performed separately for each residence, based on the number of sanitary wares and devices used, employing the formula a x b = C (Table 6).

Table 6 Cost Calculation of the Criteria for Water Saving

Formula	Number of sanitary wares used	Unit price including assembly (USD)	Total cost (USD)
a x b =C	a	b	C

Residential projects were compared to conventional construction methods by examining three categories: energy consumption, material usage, and water consumption practices, to facilitate comparisons with green buildings. Traditional construction practices do not require energy or water-saving measures; thus, selections are based on owner or contractor preferences. Therefore, the categories were analyzed under energy and water consumption aspects for traditional practices.

In energy-related practices, photovoltaic solar panels were excluded from the traditional energy category since they are not commonly used in low-rise buildings traditionally constructed in the Çay Bağları area. For windows, double-glazed windows commonly used in traditional buildings were considered, with prices sourced from the private sector. According to the B.E.S.T-Residential certification, A-class or higher appliances are required (washing machine, dishwasher, and refrigerator). However, traditional construction usually overlooks this criterion. Thus, for traditional practices, class C appliances were selected due to their lower costs.

For material usage in traditional buildings, facade materials without any certification (standard plaster, rock wool insulation board, and silicone exterior paint) were employed. Costs were calculated by multiplying external wall measurements (g) by the material unit price (h) (Table 5), using unit prices provided by the Ministry of Environment, Urbanization, and Climate Change.

For water consumption practices, conventional sanitary fixtures and household appliances meeting optimal requirements for daily usage were selected instead of water-saving alternatives. Costs were calculated using the unit price list of the ministry with the formula a x b = C (Table 6).

In the case study, cost analyses for detached low-rise residential buildings in the Çay Bağları area were conducted, comparing green certification system criteria and certified construction materials with traditional construction methods and materials against traditional construction methods and materials. The resulting cost differences were comparatively analyzed.

To evaluate the economic robustness of the proposed photovoltaic systems, a simplified scenario-based sensitivity analysis was conducted. Electricity prices and photovoltaic system costs were varied by ±20% to examine their potential effects on annual savings and payback periods under changing market conditions. This approach allowed the assessment of the sensitivity of payback periods to changes in key economic parameters.

3. Results

3.1. Cost Findings Related to Green Building Practices

Green building measures included water-saving fixtures, efficient appliances, solar panels, insulated windows, and EPD-certified facade materials. Based on these criteria, traditionally constructed low-rise residential buildings were evaluated according to green building practices, and related cost data were generated.

Cost data regarding products, materials, and practices evaluated within the categories of water, energy, and material conservation were obtained through private-sector research. Cost calculations were performed individually for each of the three residential buildings in Kayseri's Çay Bağları area, and comparative analyses between buildings were conducted.

Cost findings related to water saving practices in buildings

For the cost analysis of water-saving practices, sanitary installations with low water consumption, water-efficient faucets, and sanitary wares (wall-mounted toilets, concealed cisterns) meeting green building certifications were selected. Additionally, water-efficient appliances (washing machines and dishwashers) with A-class energy ratings, as recommended in the B.E.S.T-Residential certification guidelines, were selected.

In the first residence, among water-saving practices, washbasin faucets had the lowest unit cost, while sanitary fixtures (wall-mounted toilets, concealed cisterns) had the highest unit cost. When considering the total cost of the building, the sanitary wares significantly influenced the overall expenses due to their quantity. Additionally, due to selecting water-efficient appliances with A-class energy ratings, these products' prices were higher compared to standard appliances (Table 7). Sanitary fixtures accounted for 39.3% of total water-saving costs, followed by the dishwasher (22.0%) and washing machine (17.9%). The kitchen faucet had the smallest share at 3.9%.

Table 7 Cost Analysis for the First Building Water Saving

	Water-Saving Practices	Unit Price (USD)	Quantity	Total Cost (USD)
Water-Efficient Sanitary Wares	**Kitchen Faucet** -With special flow throttling aerator, max. 5 L/min water flow and is in the lowest consumption group. -European Water Labelling Class: Dark Green (0 < Flow rate ≤ 6)	201	1	201
	Washbasin Faucet -With special flow throttling aerator, max. 5 L/min water flow and is in the lowest consumption group. -European Water Labelling Class: Dark Green (0 < Flow rate ≤ 6)	147	6	882
	Sanitary Fixtures **Wall-mounted toilet & concealed cistern)** According to the European Union norms, it is approved as the lowest water consumption toilet bowls that function with 2.5/4 L of water.	408,6	5	2043
Water Efficient Devices	**Dishwasher** -Water consumption 9.5 L -A energy class -Energy consumption 0.503 kWh	1144	1	1144
	Washing Machine -Water consumption 40 L (1 cycle) -A energy class -Energy consumption 34 kWh (100 cycles)	932	1	932

Total: 5202 USD

Water-saving costs were lower in the second and third residences due to fewer installed faucets and toilets. Across all three residences, the kitchen faucet had the lowest contribution to the total cost, whereas the dishwasher had the highest contribution. In the second and third residences, sanitary fixtures represented 36.3% of total water-saving costs, while the dishwasher (25.4%) and washing machine (20.7%) together accounted for nearly half of total expenditure.

Table 8 Cost Analysis for the Second and Third Buildings Water Saving

	Water-Saving Practices	Unit Price (USD)	Quantity	Total Cost (USD)
Water-Efficient Sanitary Wares	**Kitchen Faucet** -With special flow throttling aerator, max. 5 L/min water flow and is in the lowest consumption group. -European Water Labelling Class: Dark Green (0 < Flow rate ≤ 6)	201	1	201
	Washbasin Faucet -With special flow throttling aerator, max. 5 L/min water flow and is in the lowest consumption group. -European Water Labelling Class: Dark Green (0 < Flow rate ≤ 6)	147	4	588
	Sanitary Fixtures **Wall-mounted toilet & concealed cistern)** According to the European Union norms, it is approved as the lowest water consumption toilet bowls that function with 2.5/4 L of water.	408,6	4	1634,4
Water Efficient Devices	**Dishwasher** -Water consumption 9.5 L -A energy class -Energy consumption 0.503 kWh	1144	1	1144
	Washing Machine -Water consumption 40 L (1 cycle) -A energy class -Energy consumption 34 kWh (100 cycles)	932	1	932

Total: 4499,4 USD

Cost findings for energy-saving practices in residential buildings

For the cost assessment of energy-saving measures in residences, photovoltaic solar panels converting solar energy into electricity, insulated windows minimizing heat exchange, and energy-efficient household appliances were considered. As the required data could not be found in the ministry's unit price list, market research was conducted to obtain current data from private sector firms for each item.

To calculate the costs of photovoltaic solar panels, the characteristics and costs of the panels were determined by consulting specialized private sector firms, and relevant project documents were shared with these firms. Annual electricity generation and consumption values for each residence, panel specifications, the proportion of electricity consumption supplied by solar energy, environmental benefits, and the system cost were determined. Panels were designed primarily to meet the internal electricity demand of the residences. A Grid-Connected System (ON-GRID) was arranged to transfer any excess energy back to the grid. Panels with a capacity of 540 Wp are typically preferred in detached residential buildings in Kayseri. For optimal efficiency, panels must primarily be oriented toward south, east, or west directions.

For the cost calculations of insulated windows, windows with triple glazing, 84 mm-wide PVC profile systems, 7-chamber profiles, and low thermal transmittance values (U=0.90 W/m²K) were selected. Window and door measurements of each residence were determined, and total costs were calculated using data from a private company based in Kayseri.

Regarding energy-efficient household appliances, the B.E.S.T-Residential certification guidelines require the selection of refrigerators, washing machines, and dishwashers classified as "A" energy class or higher. In this study, costs were calculated using appliances classified as energy class A.

However, due to the absence of class-A refrigerators during the market research, refrigerators were excluded from the cost assessment. Additionally, since the certification specifies only washing machines, dishwashers, and refrigerators, other household appliances were excluded from the scope of this study.

For the first residential building, photovoltaic solar panel calculations were performed based on assumptions listed in Table 9. A total of 15 panels, each with a power rating of 540.00 Watts and a DC installed power of 8.10 kWp, were used (Figure 17).

Table 9 Assumptions Used in Photovoltaic Panel Calculations for the First Residence

Assumption	Value
Average monthly electricity consumption	972 kWh
Energy purchase price	0.17 USD/kWh
Annual potential electricity price increase	35%

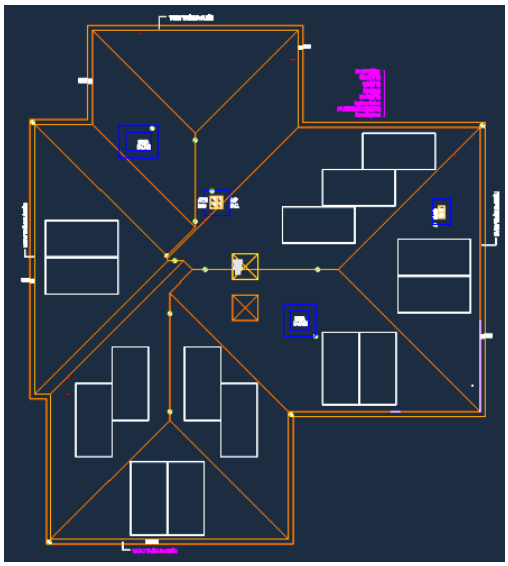

Figure 17 Illustrates the photovoltaic panel layout plan for the first residence (Solimpeks, 2024)

Annual electricity production and consumption values for the residences were calculated automatically based on international databases and regional solar radiation data. According to the calculations, annual solar-generated savings amounted to 1668 USD, electricity purchased from the grid cost 476 USD, and excess electricity sold back to the grid amounted to 104,65 USD. The total savings were thus calculated as 1572,5 USD, with a payback period of 5.25 years (Solimpeks, 2024).

In Kayseri, where the first residence is located, surplus energy produced during summer months is sold back to the grid. While 83% of the building's electricity demand is covered by solar energy, 17% is supplied from the grid. As a result, substantial energy savings were achieved. Additionally, the renewable energy system reduces annual CO_2 emissions by approximately 3.59 tons/year, equivalent to saving around 582 trees (Solimpeks, 2024).

For the second and third residential buildings, a single photovoltaic solar panel analysis was performed since their layouts are similar and roof areas are close in size (Table 10). The roof area of the second building is 213.76 m², while the third building's roof area is 236.22 m². Panel design and calculations were based on assumptions listed in Table 10. In both the second and third buildings, 17 panels with a unit power of 540.00 W and a total DC-installed capacity of 9.18 kWp were used (Figure 18).

Table 10 Assumptions used in Photovoltaic Panel Calculations for the second and Third Residences (Solimpeks, 2024)

Assumption	Value
Average monthly electricity consumption	1100 kWh
Energy purchase price	0.17 USD/kWh
Annual potential electricity price increase	35%

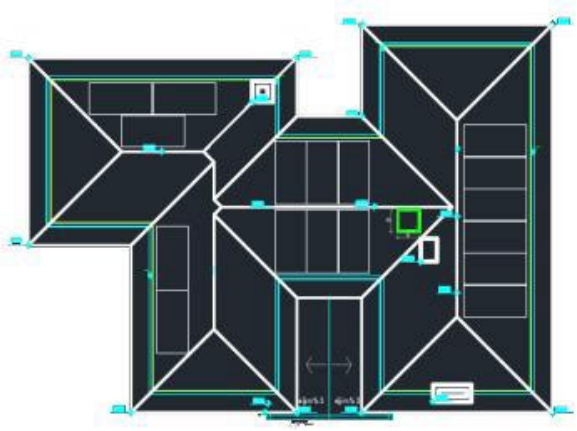

Figure 18 Illustrates the photovoltaic panel layout plan for the second and third buildings (Solimpeks, 2024)

Annual electricity production and consumption values of these residences were automatically calculated based on international solar radiation data specific to the region. According to the calculations, solar energy savings were 1662,5 USD, electricity purchased from the grid cost 537,5 USD, and excess electricity sold back to the grid amounted to 119,5 USD. Total savings were thus 1782 USD, with a payback period of 4.5 years (Solimpeks, 2024).

As with the first building, surplus energy generated during summer months in the second and third residences is sold back to the grid. Approximately 83% of the electricity demand was met by solar energy, with the remaining 17% from the grid, resulting in significant energy savings. Moreover, renewable energy systems reduced CO_2 emissions by 4.07 tons/year, equivalent to approximately 660 trees saved annually (Solimpeks, 2024).

For the window cost analysis, measurements of the three buildings were taken. A detailed cost list was generated for windows characterized by 84 mm wide PVC profile systems, featuring seven chambers, triple glazing, and low thermal transmittance values (U=0.90 W/m²K) (Solimpeks, 2024).

Across all three buildings, the frame casing and the S series triple-glazed window system (4+12+4+12+4) were the primary contributors to total window costs due to their substantial impact on energy conservation. Perimeter locking hardware had the lowest impact on costs. The third building exhibited the lowest total window cost, primarily because fewer windows were used compared to the other two residences. The S series triple-glazed systems substantially reduce heat loss compared to standard glazing, leading to decreased fuel consumption and energy savings.

In the cost study regarding energy-efficient appliances, household appliances with identical features were selected for each of the three residential buildings. According to the B.E.S.T-Residential guidelines, these appliances must be classified at least as energy class "A" or higher. Class-A-rated appliances were therefore selected, and their prices were sourced from the private sector. However, refrigerators were excluded because they were unavailable as class-A products during the market research. Additionally, since the B.E.S.T-Residential guidelines specify criteria only for washing machines, dishwashers, and refrigerators, other household appliances were excluded from this research.

The cost analyses for photovoltaic solar panels, insulated windows, and energy-efficient appliances for each residence are summarized below:

First Building Energy Conservation Cost Analysis:

Among energy conservation practices, photovoltaic solar panel implementation has the most significant influence on total costs, followed by insulated windows, dishwashers, and washing machines, respectively. Energy-saving measures dominated overall green building costs, representing 67.1% of total expenditure for the first building.

A sensitivity analysis was conducted to evaluate the impact of electricity price and photovoltaic system cost on economic performance. The results indicate that increases in electricity prices enhance the economic value of self-generated energy and reduce payback periods, whereas higher photovoltaic system costs lead to longer payback durations (Table 11).

Table 11 Sensitivity Analysis for the First Building

Scenario	Change	Estimated Payback Period (years)
Base Case	**-**	**5.25**
Electricity +20%	Price ↑	4.38
Electricity -20%	Price ↓	6.56
PV Cost +20%	Cost ↑	6.30
PV Cost -20	Cost ↓	4.20

The cost analysis for the second residence indicates that the lowest-cost component among energy-efficient appliances was the washing machine, whereas photovoltaic solar panels had the most significant impact on the total cost. Although less influential than photovoltaic systems, insulated windows also contributed considerably to the overall cost. Energy-saving practices accounted for 59.0% of total green building costs in the second residence.

Third Building Energy Conservation Cost Analysis:

Similarly, in the third building, photovoltaic solar panels represented the highest-cost component, consistent with the findings for the first and second residences, while energy-efficient appliances had the least impact. Despite the third residence having a larger total construction area (537.01 m²) compared to the first residence (328 m²), its total cost related to energy conservation was lower. This suggests that energy conservation costs may not increase proportionally with building size. Energy-related costs constituted 60.2% of total green expenditure in the third building.

To further evaluate the impact of key parameters such as electricity price and photovoltaic system cost on economic performance, a sensitivity analysis was conducted, indicating that increases in electricity prices enhance the economic value of self-generated energy and reduce payback periods, whereas higher photovoltaic system costs lead to longer payback durations (Table 12).

Table 12 Sensitivity Analysis for the Second and Third Buildings

Scenario	Change	Estimated Payback Period (years)
Base Case	-	4.50
Electricity +20%	Price ↑	3.75
Electricity -20%	Price ↓	5.63
PV Cost +20%	Cost ↑	5.40
PV Cost -20	Cost ↓	3.60

The sensitivity analysis indicates that increases in electricity prices significantly reduce the payback period, while increases in photovoltaic system costs extend it. A ±20% variation in electricity prices is lead to noticeable changes in annual savings, whereas variations in PV system costs directly influence initial investment and payback duration. These findings suggest that economic feasibility is more sensitive to energy price fluctuations in the long term.

Although the payback period was calculated for photovoltaic systems, a comprehensive life-cycle cost analysis covering all building components was not included within the scope of this study. Such analyses could provide a more detailed understanding of long-term economic performance and are recommended for future research.

Cost findings related to material usage in residential buildings

Materials with EPD certification, required by major green standards, were chosen for the cost analysis in these residences. The external façade was constructed sequentially using Probase Matik

cement-based plaster, rock wool insulation, Probase render primer plaster, Probase mineral decorative coating plaster, and silicone-based exterior paint. A 7-cm thick rock wool insulation with perpendicular tensile strength of 10 kPa and thermal conductivity of 0.036 W/mK was applied over the cement-based ready-mixed machine plaster (Probase matik). Subsequently, Probase render primer plaster conforming to TS EN 998-1 standards, Probase mineral-based decorative plaster, and EPD-certified silicone-based exterior paint were used (Dalsan, 2025; Dyo, 2025).

To calculate the cost of EPD-certified construction materials for the sample residences, first, external wall measurements were first calculated using the formula (d x e) - f = G, where the building height (d) was multiplied by the perimeter (e), subtracting openings such as windows and doors (f). As the heights and perimeters of ground and first floors were not identical, they were calculated separately. Since prices for these certified products were unavailable from the Ministry of Environment, Urbanization, and Climate Change unit price list, data from private sector companies were utilized. The total material costs (I) were then calculated by multiplying the external wall area of the building (g) by the unit price of each material (h) (Table 13).

Table 13 Cost Analysis of Three Buildings for Material Usage

Building	Total cost (USD)
1st Building	10592,16
2nd Building	14242,5
3rd Building	14792

Across all three buildings, EPD-certified rock wool insulation was consistently the most cost-influential material, owing to both its high unit price and its significant contribution to energy savings through reduced heat loss. Cement-based plaster ranked second in terms of cost impact, while mineral decorative plaster and silicone-based exterior paint had the least influence on total costs. The total costs of decorative plaster and silicone-based exterior paint were relatively close across all residences.

3.2. Cost Findings Related to Traditional Construction Practices

In this section, the costs of three detached residential buildings were calculated and evaluated within the framework of traditional construction practices have been calculated and evaluated. For fair comparison, traditional buildings were analyzed using the same water, energy, and material categories as in the green study. However, the selection of products, materials, and practices for the three residential buildings in the Çay Bağları area does not require compliance with the specific standards mandatory for green buildings. Materials for traditional buildings were chosen based on affordability and local construction norms to reflect typical usage.

Cost findings related to water consumption in residential buildings

While low-flow sanitary fittings and water-efficient appliances are selected in green building practices, traditional construction practices do not specifically consider criteria for water and energy conservation. To enable a direct comparison, while A-class energy-rated appliances were selected for green building practices, class-C appliances were chosen for traditional practices. In traditional construction, medium-class priced products were selected for household appliances, sanitary fittings, and sanitary ware.

Although Çay Bağları is typically home to upper-income residents with diverse and high-end preferences, this study selected traditional construction materials with optimal costs to allow fair comparison with green building practices (Table 14). Top-quality washbasin faucets were therefore not used in the cost calculation for water consumption; only price variations in the product range based on preference were presented (Table 14).

Among practices related to water consumption, washbasin faucets had the lowest unit cost, whereas dishwashers exhibited the highest cost. The share of each product in total costs varied depending on the quantity used in each residence. In the first building, the total costs of household

appliances (washing machine) and washbasin faucets were relatively close. In contrast, the second and third residences had fewer washbasin faucets, resulting in lower total costs compared to washing machines. The first residence had higher total costs than the others, primarily due to the greater quantity of faucets and sanitary fittings installed (Tables 14 and 15).

Table 14 Cost Analysis for the First Building Water Use

	Practices for water consumption	Unit Price (USD)	Quantity	Total Cost (USD)
Sanitary Wares	**Kitchen Faucet**	159	1	159
	Washbasin Faucet	85	6	516
	Top Quality Washbasin Faucet	643	6	3858
	Sanitaryware Elements (Set Toilet)	180	5	900
Devices	**Dishwasher**	819	1	819
	Washing Machine	608	1	608

Total: 6860 USD

Table 15 Cost Analysis for the Second and Third Buildings Water Use

	Practices for water consumption	Unit Price (USD)	Quantity	Total Cost (USD)
Sanitary Wares	**Kitchen Faucet**	159	1	159
	Washbasin Faucet	85	4	344
	Sanitaryware Elements (Set Toilet)	180	4	720
Devices	**Dishwasher**	819	1	819
	Washing Machine	608	1	608

Total: 2650 USD

Cost findings related to energy consumption in residential buildings

In traditional residential construction, windows and household appliances were selected based on conventional specifications without adherence to green certification criteria. Double-glazed windows commonly used in the region were considered, and class C appliances were selected due to their lower costs compared to the A-class appliances required in green building practices.

Among the three residences, the third building had the highest window-related costs, followed by the first and second, indicating that window costs directly correlate with both the number of units and their technical specifications. Although appliances were cheaper per unit, window costs were higher due to their greater quantity. Appliance costs (dishwasher and washing machine) were identical across all buildings, since products with similar specifications were used.

In this context, the main factors influencing energy-related costs in traditional residences include window specifications, the number of window units, and appliance selection. Accordingly, the total energy-related costs for the three buildings are summarized in Table 16.

Table 16 Cost Comparison of Three Buildings for Energy Consumption

Building	Total cost (USD)
1st Building	11050
2nd Building	10448
3rd Building	11592

Cost findings related to material consumption in residential buildings

Residential buildings constructed in the Çay Bağları area are predominantly built using traditional reinforced concrete structural systems. Common external facade finishes include rough plaster, 6 cm-thick insulation, primer plaster, and exterior facade paint, applied sequentially. These local materials were selected for calculating material costs under traditional building practices. Unlike the environmentally certified materials used in green buildings, as specified in global certification systems, the materials selected for traditional construction do not possess any

environmental certification. The unit price list published by the Ministry (January 2024) and private-sector market data were used for cost calculations.

The external wall areas of the three sample buildings were used as a basis for calculating total material costs the external wall measurements are consistent with those previously calculated for the green building cost analyses.

Across all three buildings, rock wool insulation exhibited the highest unit cost among exterior facade materials, followed by rough plaster, mineral decorative plaster, primer plaster, and exterior paint. In the first building, total rock wool insulation costs amounted to 3,621 USD, whereas exterior paint costs amounted to 850 USD, highlighting the significant cost impact of insulation (Table 17). As the external wall area increased across the three buildings, from 314.87 m² (first) to 422.98 m² (second) and 439.3 m² (third), total material costs rose proportionally, from 9,320 USD to 12,520 USD and 13,003 USD, respectively. The unit cost per square meter remained nearly constant at approximately 29.5–29.6 USD/m² across all three buildings. Due to the similar wall areas of the second and third buildings, the cost difference between them was smaller than the difference from the first building (Table 17).

Table 17 Cost Comparison of Three Buildings for the Use of Materials

Building	External Wall Quantity of the Building (m²)	Total cost (USD)	Unit price (USD/m²)
1st Building	314,87	**9320,11**	**29,5**
2nd Building	422,98	**12520,26**	**29,6**
3rd Building	439,3	**13003,36**	**29,6**

Table 18 presents a comparative summary of total green and traditional building costs across all three residences. Energy-saving measures represented the largest share of green building expenditure (59–67%), followed by materials (22–31%) and water-saving practices (9–11%).

Table 18 Cost Comparison of Green and Traditional Building Applications for the Three Residences

	Applications	1st Building (USD)	2nd Building (USD)	3rd Building (USD)
Green Building Applications	Water-saving practices	5,204	4,500	4,500
	Energy-saving practices	32,285	26,958	29,128
	Material usage practices	10,602	14,243	14,792
	Total	**48,090**	**45,701**	**48,421**
Traditional Building Applications	Water consumption practices	3,002	2,651	2,651
	Energy consumption practices	11,050	10,448	11,592
	Material usage practices	9,352	12,565	13,050
	Total	**23,404**	**25,663**	**27,292**
	Difference (Green – Traditional)	24,687	20,038	21,129
	Percentage increase (%)	**105.5%**	**78.1%**	**77.4%**

Although the analysis primarily focuses on initial investment costs, the calculated payback periods for photovoltaic systems indicate long-term economic performance. The findings can therefore serve as a preliminary reference for life-cycle cost evaluations. Despite higher initial costs, certain green building applications, particularly photovoltaic systems, can offer economic advantages over time through reduced operational costs.

4. Discussion

Green buildings are often viewed as more expensive than traditional construction, particularly during the initial investment phase. This perception can hinder the adoption of sustainable practices despite long-term savings. In this study, low-rise residences in Kayseri's Çay Bağları district were examined to assess cost differences between traditional and green systems.

Green cost categories included water efficiency, energy efficiency, and sustainable materials. Although Kayseri lacks certified green housing, this study provides foundational data for future applications. Water-saving strategies featured low-flow faucets, efficient sanitary fixtures, and appliances. Sanitary fixtures and appliances were the most significant cost factors, with fixture quantity impacting cost regardless of unit price.

Energy-saving measures included photovoltaic panels, insulated windows, and efficient appliances. Solar panels had the highest upfront cost, while windows and appliances also contributed substantially to the aggregate. For materials, environmentally certified products such as EPD-labeled cement plasters, rock wool insulation, and eco-friendly paints were used. Rock wool insulation led material costs due to its thermal performance (EPD Türkiye, 2025).

Although initial costs were higher, green elements offer long-term benefits. Variations in roof size impacted photovoltaic installations; the smallest house had the highest unit cost, revealing non-linear cost behavior. Façade material costs increased with building size and were shaped by wall area and design. The smallest building had notably lower external finish costs.

To summarize: sanitary fixtures and appliances drove water efficiency costs; solar panels dominated energy investments; and insulation was the largest material cost. While these factors raise initial expenditure, operational and environmental gains justify the investment.

Prior research supports these outcomes. Çelik (2009) advocated for integrating global green certifications into Turkish construction but lacked practical studies. Yağcıoğlu (2018) explored water-efficient fixtures, paralleling this study's focus. Güzelkokar (2019) examined transitions to green buildings but did not detail cost analyses. Yılmazsoy (2021) emphasized sustainable housing post-COVID, a direction confirmed by this fieldwork (Çelik, 2009; Yağcıoğlu, 2018; Güzelkokar, 2019; Yilmazsoy, 2021).

5. Conclusions and Recommendations

Green building practices resulted in higher initial construction costs across all categories analyzed. The total cost of green building applications was higher than that of traditional construction in all three residences, amounting to approximately USD 48,090 versus USD 23,404 in the first residence, USD 45,701 versus USD 25,663 in the second residence, and USD 48,421 versus USD 27,292 in the third residence, corresponding to increases of approximately 106%, 78%, and 77%, respectively. Photovoltaic systems were identified as the most significant cost contributor. However, these initial expenses are offset by long-term operational savings.

To promote adoption, several stakeholder-specific recommendations are proposed:

Central Authorities: Implement financial incentives, tax reliefs, and technical support mechanisms. Establish municipal green building units and increase public awareness to stimulate demand.

Contractors: Evaluate buildings beyond initial costs by considering long-term savings. Improve awareness and training regarding green building benefits.

Architects: As design decisions influence lifecycle costs, incorporate green building education in professional training. Encourage specializations in sustainable design.

Users: Educate residents about green building benefits, including operational savings, environmental impact, and improved indoor comfort.

Material Manufacturers: Promote awareness of certified materials and their long-term advantages. Address misconceptions about cost through transparent communication and training.

In conclusion, although initial investments in green buildings are higher, these practices offer significant long-term benefits. They improve environmental performance, increase property value, and contribute to broader sustainability goals. Policymakers, practitioners, and users must

collaborate to overcome cost-related concerns and promote the widespread adoption of green buildings in Türkiye.

Although life cycle cost (LCC) is widely recognized as an important parameter in evaluating the long-term economic performance of building systems, a comprehensive LCC analysis was not included within the scope of this study. This is mainly due to the lack of reliable and consistent long-term data, such as maintenance, operation, and replacement costs, as well as appropriate discount rates.

In addition, variability in service life assumptions and the lack of standardized datasets limit the applicability of detailed LCC calculations in this context. A net present value (NPV) analysis incorporating discount rates and the time value of money was also not conducted, due to the limited availability of region-specific discount rates and long-term operational cost data for residential green buildings in Türkiye. Therefore, this study focuses on initial cost comparisons and payback-based evaluations.

Future research should incorporate long-term cost components and develop more comprehensive life cycle cost analyses, including NPV-based investment appraisal methods, to better assess the economic performance of green building applications.

The findings of this study provide practical implications for different stakeholder groups. For policymakers, the results highlight the importance of developing incentive mechanisms and regulatory frameworks to support the adoption of green building applications. For designers and practitioners, the study emphasizes the need to consider not only initial investment costs but also long-term economic benefits when selecting building components and systems. For users and investors, increasing awareness of payback periods and operational savings is crucial for more informed decision-making.

In addition, improving long-term cost awareness requires not only economic evaluation but also the dissemination of technical knowledge and training programs related to energy-efficient systems and renewable energy applications. The lack of accessible and standardized data on long-term costs remains a significant barrier to wider adoption.

Furthermore, the findings indicate that region-specific challenges and implementation gaps still exist, particularly in terms of data availability, technical expertise, and market accessibility. Future studies should focus on field-based analyses and regionally adapted models to better reflect real-world conditions and support the broader implementation of sustainable building practices.

Overall, the study demonstrates that green building applications can be evaluated not only in terms of initial costs but also in relation to their long-term economic potential.

CRediT Authorship Contribution Statement

Nurbanu Şahin: Methodology, Conceptualization, Investigation, Validation, Visualization, Writing – Original Draft. Merve Bıyıklı Hasözhan: Conceptualization, Investigation, Methodology, Formal Analysis, Validation, Visualization, Writing – Original Draft Zübeyde Özlem Parlak Biçer: Supervision, Writing – Review & Editing. All authors have read and approved the final version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

Ethics Committee Approval

Ethics committee permission is not required.

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Resume

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