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Occupants' inquiries for energy efficiency retrofitting in the Netherlands

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1. Introduction

Residential buildings contribute significantly, representing 40 % of energy consumption and 36 % of CO2 emissions in the European Union (EU) [1]. The Dutch housing stock includes 7.5 million houses. Most are heated by natural gas and have bad thermal energy conditions [2]. The Ministry of Economic Affairs in the Netherlands has introduced a new policy to promote initiatives that support individuals using renewable energy in the heating sector rather than using natural gas by 2050 [3,4]. It leads to 200,000 zero-carbon renovations per year. An extensive innovation program is being developed [2]. This transition in energy involves moving away from fossil fuels, electrifying heating needs, raising awareness among residents, and adjusting energy taxes to support renewable energies. However, several factors, such as low renovation rates, lead to uncertainties in reaching these objectives [1]. Hence, policies are to be developed to increase owners' awareness regarding the effects of energy-efficient buildings and their impact on life quality, comfort, and health conditions through improving ventilation and decreasing condensation [1]. Moreover, the design of policies to encourage energy renovations, and enhance the quality of residential buildings and indoor air quality is essential to most of the EU countries and worldwide [5]. Occupants' active involvement is crucial in pursuing sustainable and energy-efficient housing. This study explores the level of occupants' contribution and factors influencing participation in energy-efficient retrofitting (EER). It examines the influential factors that shape occupants' energy-related participation and their decisions regarding energy renovation initiatives. The central research question driving this study is to determine which factor plays a more significant role in motivating occupants to take action towards EER by providing the support and advice of the experts. The results of this research will shed light on occupants' awareness of energy efficiency approaches and ascertain the impact of such attention on their decision-making process when considering energy-efficient technology implementations.

2. State-of-the-art

2.1. Energy retrofitting inquiries (ERI) rate measurement

A holistic approach involving three design teams is essential to achieve energy-efficient buildings. The first team focuses on the building envelope, which includes aspects like insulation and materials used in construction. The second team deals with building services such as ventilation, space heating, energy production, and water systems. The third team focuses on user interaction, considering factors like monitoring energy usage, user acceptance, and interfaces [6]. This study has developed ERI indicators to assess the energy efficiency of buildings during the retrofitting process. These indicators include building envelope insulation (BEI), building services (BS), and building installation (BI). They serve as essential considerations in evaluating the retrofit potential of a building. To measure the ERI rate, this study considers three main influential factors. The first factor is building characteristics, which include age, size, and type of building. The second factor is occupant profiles, which consider the behavior, preferences, and needs of the people living or working in the building. The third factor is policies and incentives, which motivate individuals and organizations to take action in energy transitions and adopt energy-efficient retrofit practices. By understanding and addressing these factors, policymakers and stakeholders can develop effective strategies to encourage EER and facilitate the energy transition process (Fig. 1).

2.1.1. Building characteristics perspective

The essential building characteristics determining the EER strategy include floor, walls, roofs, windows, and energy systems [5,7]. The retrofitting efforts in the Netherlands have been aimed at improving various aspects of energy performance in residential buildings. These include upgrading the level of insulation, installation of energy-efficient heating systems, and adoption of renewable energy technologies. One notable aspect of the retrofitting initiatives is the emphasis on insulation. Buildings have undergone insulation upgrades for walls, roofs, and floors, reducing heat loss and enhancing thermal comfort. Additionally, advanced window glazing technologies with low thermal

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transmittance have been widely adopted to minimize energy losses further. The implementation of energy-efficient heating systems has been another key focus area. ERBs in the Netherlands commonly feature high-efficiency boilers, heat pumps, and district heating systems. These technologies offer improved performance, reduced energy consumption, and decreased greenhouse gas emissions. Renewable energy integration has also played a significant role in the retrofitting process. Many ERBs now incorporate photovoltaic panels on rooftops to generate electricity, while others employ solar thermal systems for water heating. These renewable energy solutions contribute to the overall energy self-sufficiency of the buildings and reduce reliance on conventional energy sources. Since the concerted efforts to enhance energy efficiency in the Dutch housing stock have yielded promising results, this section briefly describes the characteristics of energy-efficient retrofitted buildings (ERBs) in the Netherlands, according to the report of Woon Energie [8].

Over the past 18 years, there has been a gradual improvement in the energy efficiency of the Dutch housing stock. Each house is assigned an Energy Index (EI) that determines its energy label, serves as an indicator of the home's energy efficiency level, and suggests potential energy-saving measures. The grading ranges from G, indicating the least efficient, to A++++, meaning the highest energy efficiency [9]. An energy label is mandatory for the sale, rental, or substantial renovation of homes, in adherence to European regulations. This requirement applies to both new constructions and existing structures, and the issued label remains valid for a decade. A qualified Energy Performance (EP) advisor calculates the energy label, considering various factors like insulation, glazing, heating, cooling, technological installations, solar panels, and ventilation [10]. The distribution of the housing stock across energy labels shows a decrease in the number of homes with potential energy savings (labels E, F, and G) and an increase in the most energy-efficient homes (labels A and B) [8].

The Dutch housing stock is divided into owner-occupied and rental sectors, constituting 69.4 % and 30.6 %, respectively. Despite expectations of higher renovation rates in the social housing sector, the results indicate nearly equal renovation rates across all three sectors [11]. From 1980 onward, insulation has become standard in newly constructed homes. In contrast, older homes show less frequent insulation across various building components, resulting in notable variations based on construction years. In these older homes, insulation is more commonly found in roofs and windows, while floors and facades are less frequently insulated. Approximately 77 % of the surface areas of residential components, on average, are insulated. An insulation degree of 100 % does not necessarily mean no room for improvement. Owner-occupied homes have the highest average insulation degree at 80 %, followed by corporation homes at 73 %, and private rental housing has the lowest at 61 %. Newly constructed houses (built from 1980) typically have complete insulation, while older homes (until 1960) exhibit lower insulation levels. Roofs and glass parts of homes are mostly insulated, with average insulation degrees of 86 % and 85 %, respectively. In contrast, floors (63 %) and facades (73 %) are less frequently insulated. Since 2006, there has been an increase in houses with promising energy labels, partly due to additional insulation in roofs, floors, facades, and glass. The insulation level has risen in both owner-occupied and rental properties. However, in private rental homes, the average insulation level of roofs and floors remained relatively constant between 2012 and 2018. Regarding heating installations, most owner-occupied homes (87 %) use high-efficiency boilers (HR), predominantly HR107 boilers. Improved efficiency (VR) boilers or local heating sources are more common in private rented houses. Rental houses often rely on high-efficiency boilers and collective heating. The number of houses with hybrid or all-electric heat pumps has significantly increased, especially in well-insulated homes with energy label A. However, many homes labeled as A (or A+ / A++) still need to be equipped with a heat pump, indicating a high potential for application, especially with improved insulation in the future [8].

2.1.2. Occupants' perspective

Despite the pressing need for retrofitting, the renovation rate and subsequent energy savings remain relatively low. The primary obstacles identified are linked to the availability of investment funds, lack of awareness, limited access to advice and expertise, and the disconnect between renovation costs and its benefits [12]. Retrofitting residential buildings for energy efficiency faces various risks, resulting in slow progress in retrofit development. Most risks relate to owners and contractors, covering areas such as awareness of retrofitting, collaboration performance, opportunism, expertise, construction and safety management, and maintenance. Insufficient awareness, inadequate collaboration, and opportunistic behaviors among owners adversely affect project performance [13]. The involvement of the occupant is crucial not just during the post-renovation phase but also during the design and planning stages of the renovation. This is especially important as there is a growing demand to improve both the physical condition and performance of the building while minimizing disruptions to the interior, thus avoiding the need for occupants to be temporarily relocated during construction. Additionally, occupant satisfaction plays a significant role in successfully implementing retrofitting efforts [14]. Hence, retrofitting the building stock is a multifaceted undertaking that requires careful consideration of various aspects, influencing the approach taken for each building [6].

Regarding occupants' behaviors in the energy efficiency renovation, the research on Dutch housing stock indicates that education level plays a significant role in influencing decisions related to energy-efficient renovations, with higher-educated individuals demonstrating a greater inclination for renovation compared to those with lower levels of education [15]. Homeowners usually need to follow different phases in the renovation process. The steps include consideration, strategic planning, decision-making, execution, and the experience [16,17]. In this study, we have classified them into pre-renovation, during-renovation, and post-renovation phases. Transaction costs (TCs) are non-monetary expenses linked to various stages of the homeowner's renovation process. Recognized as a key obstacle to reaching energy efficiency goals, these costs are demonstrated in various ways, including time, effort, difficulties in renovation tasks, inconveniences, disruptions, and

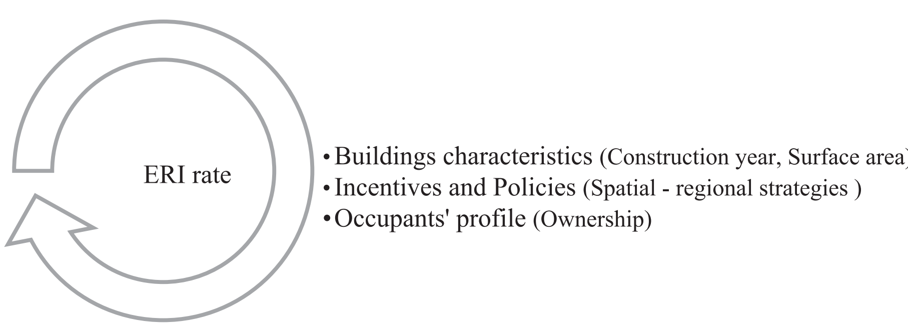

Fig. 1. Influential factors in ERI rate.

uncertainties. TCs are unavoidable, typically unpredictable, and can potentially extend the renovation process's duration, requiring additional effort [16,18,19]. For both renovators and potential renovators, the main TC barrier determines the best ways to increase the energy efficiency of the houses [15]. The primary transaction cost (TC) obstacles identified during the phases of considering, deciding, and executing renovation decisions are locating a trustworthy professional/contractor for exterior renovations, assessing expenses for interior renovations, and discovering methods to enhance the house's energy efficiency through energy-saving renovations. Moreover, maintenance/installation companies influence energy efficiency renovations for both renovators and potential renovators [19]. This study has investigated the ERI rate of occupants in different phases of a renovation process, including consultation, installation, inspection, and maintenance of energy-efficient technologies (Fig. 2).

In the Netherlands, achieving an agreement among 70 % of tenants in a building for the renovation process is often challenging and only sometimes accomplished [20]. Furthermore, even if a renovation is successfully implemented, rebound effects frequently occur, leading to higher actual energy consumption than initially predicted in calculations [21]. The specific reasons for these rebound effects are still unclear. Still, it is believed that they may be attributed to the post-renovation behavior of residents and their interaction with home systems [22]. In the context of the Netherlands, the concept of "zero on the meter" (nul-op-de-meter) refers to a building, typically a social housing renovation project, where the annual energy consumption of the building and its occupants is balanced by the renewable energy generated within the building and its surrounding area, such as through the utilization of rooftop photovoltaic panels [23].

The housing stock in the Netherlands is divided into two sectors: owner-occupied and rental (comprising social housing and private rental houses), accounting for 69.4 % and 30.6 %, respectively. Remarkably, the renovation rates in these three sectors are nearly identical despite the initial anticipation of higher renovation rates in the social housing sector [11]. The insulation levels vary among different types of homes, which can be attributed to ownership status. Owner-occupied homes have the highest average insulation degree at 80 %, followed by corporation homes at 73 %, and private rental homes have the lowest percentage at 61 %. The insulation level for roofs and floors is highest in owner-occupied dwellings and lowest in private rental homes. The average insulation level for facades and glass parts is similar between owner-occupied and housing association homes but significantly lower for private rental housing. Since 2006, there has been an increase in the number of houses with promising energy labels, which can be partly attributed to additional insulation measures for roofs, floors, facades, and glass. The degree of insulation has improved in both owner-occupied and rental properties. However, the average insulation levels for roofs and floors remained relatively unchanged in private rental homes between 2012 and 2018. The heating systems and hot water appliances in owner-occupied homes primarily rely on high-efficiency boilers, specifically HR107 boilers, which account for 87 % of these homes. HR100 and HR104 boilers are rarely utilized, while CR and VR boilers are occasionally seen. In the case of privately rented houses, VR boilers or local heating systems (such as oil, gas, or wood stoves) are more commonly employed than the rest of the housing stock. However, high-efficiency boilers are still prevalent in rental houses. Collective heating systems like block or district heating are frequently used in private rental dwellings and housing association homes. Heat pumps are installed in less than 2 % of owner-occupied homes [8].

2.1.3. Policy and incentive perspective

The growing significance of sustainable retrofitting and the shift towards energy conservation through behavioral change can be attributed to policy initiatives [24]. The achievement of decarbonizing the EU building stock by 2050 is only possible with strong policy support for retrofits [25]. To design practical strategies for promoting energy conservation measures in the residential sector, policymakers must be well informed about various aspects of buildings, such as their condition, occupancy, and performance. They should also consider factors like heating systems, heating behavior patterns, and the cost and availability of retrofit measures. By understanding these factors, policymakers can enhance retrofit rates through regulatory measures and tax incentives. However, it is crucial to tailor these approaches to address the key determinants of EER. Neglecting homeowners' decision-making processes when implementing EER can lead to poor policy outcomes. Therefore, it is essential to consider behavioral factors and identify the motivators and barriers influencing households' choices regarding EER [26].

The Netherlands' energy-saving policy for buildings, established in 1995, forms the basis for subsequent initiatives such as the "National Plan on Neutral Energy Building" (National Plan) introduced in 2011.

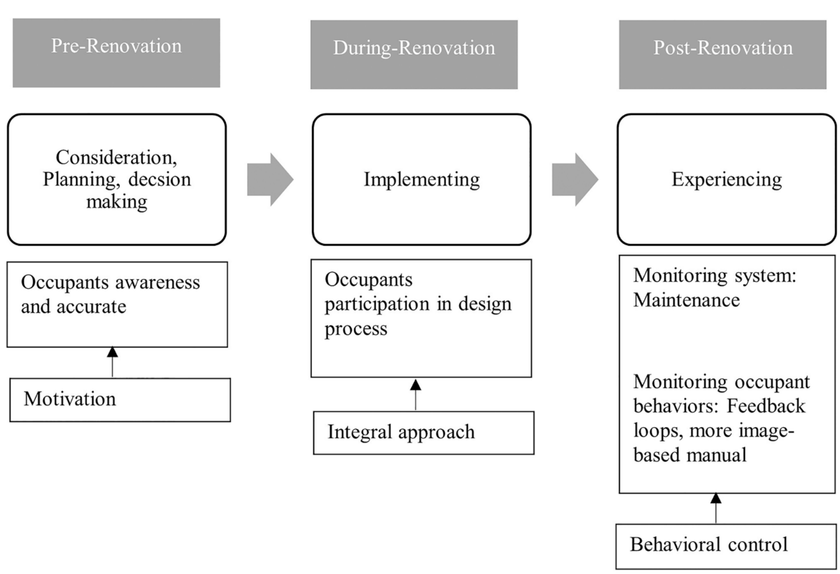

Fig. 2. Occupants' behaviors consideration in the three stages of the EER process [6,37,43].

The government's "Green Deals," initiated in 2011, facilitate agreements to overcome energy-saving barriers, involving various entities. The "Energy Agreement 2013," signed by over 40 parties, introduces measures like affordable credit for homeowners, funding for energy-saving in social housing, and enhanced requirements for new buildings. The agreement also mandates annual improvements to 300,000 existing buildings through voluntary energy agreements, reinforcing existing energy-saving obligations [27].

There are different policies and approaches implemented by different municipalities in the Netherlands. While some national policies and regulations provide a framework for energy transition, municipalities have particular instructions to develop strategies and initiatives based on local priorities, resources, and conditions. This means that policies related to the energy transition, including those targeting building retrofitting, may vary from one municipality to another. Local governments may develop specific programs, incentives, or regulations tailored to their local context and the needs of their communities. These policies range from financial incentives for energy-efficient renovations to establishing energy cooperatives or promoting renewable energy sources. The diversity of municipal-level policies allows for flexibility and the ability to address local challenges and opportunities effectively.

As aforementioned, the energy crisis has created a sense of urgency to prioritize the EER of buildings. This issue is particularly relevant for a significant portion of households in Dutch municipalities, with approximately 3.8 million households (48 %) living in homes with low energy quality. These households need help in improving the energy efficiency of their homes due to limited resources, as they rely on landlords or need more financial capital as homeowners. Consequently, they experience rising energy costs, persistent discomfort, and potential health issues related to poor housing conditions, such as moisture and mold. By implementing targeted policies to enhance the energy efficiency of more homes, these problems can be addressed, and positive outcomes will be achieved. These include reducing financial hardships, providing better housing conditions for a more significant population segment, mitigating health concerns, and accelerating the energy transition. The fact that nearly half of all households in the Netherlands cannot independently participate in the energy transition within the built environment highlights the importance of not solely focusing on addressing affordability issues for low-income households. It is evident that the current dominant energy transition policy framework in the Netherlands, which primarily aims to alleviate financial burdens and incentivize energy-efficient renovations for homeowners, does not cater to the situation of this substantial group of households who lack the choice to participate in the energy transition. However, research by Mulder et al. [28] indicates that the assumption underlying this approach that individual homeowners can organize and finance their home renovations is only applicable to approximately half of the households in the country. Consequently, different policies are required to address the needs of the remaining half. For many tenants within this group, effective policies should involve establishing performance agreements, including insulation standards, with social housing associations and private landlords in the rental sector. For homeowners within this group, facilitating access to targeted financing options and providing objective information on improving home insulation are crucial measures that should be implemented. By adopting a more inclusive approach and tailoring policies to the diverse circumstances of households, it can be assured that the energy transition extends to all sectors of society. An analysis of energy poverty patterns in the Netherlands has shown significant spatial variations, indicating that energy poverty is more geographically concentrated than income poverty. Unlike income poverty, the prevalence of high energy poverty rates is currently limited to fewer districts and neighborhoods, enabling more targeted policy interventions at the municipality or regional level. However, in contrast to income poverty, energy poverty is not primarily limited to urban areas. On the contrary, in the Netherlands, energy poverty is prevalent in underprivileged and non-urban regions, particularly when considering low-income combinations and low energy efficiency in housing as indicators of energy poverty [28].

The potential of using data to help improve policymaking is increasingly recognized by governments, primarily to address societal challenges. One of those societal challenges is the energy transition, which happens mainly at the local government level. Local governments play a vital role in implementing and achieving the energy transition. The study of Diran et al. has explored the role of data-driven applications in supporting policymaking for the local energy transition and conducted a multiple-case study focusing on the Netherlands. The primary users of these applications are policymakers, with limited applications targeting citizens and other stakeholders within the municipality. The findings reveal that data-driven applications are utilized across the entire policy cycle. Nevertheless, a notable disparity exists between the current data-driven applications implemented to facilitate and expedite the energy transition and the desired applications. Therefore, developing integrated and actionable adoption strategies to bridge this gap effectively [29].

To address climate change, the Dutch government aims to decrease greenhouse gas emissions by 49 % by 2030, relative to 1990 levels, and achieve a 95 % reduction by 2050. These targets are specified in the Climate Act enacted in 2019 [30,31]. The energy transition is not limited to individual municipalities but involves collaboration among various parties in 30 energy regions across the country. These regions are actively working on developing Regional Energy Strategies (RES) in partnership with social organizations, businesses, and residents to find mutually acceptable solutions. The RES is aligned with the spatial policies of governmental bodies, with provinces and municipalities overseeing spatial quality. The central government guides the National Environmental Vision (NOVI) and supports the implementation efforts of provinces, water boards, and municipalities [32]. This research contributes to our understanding of the role of individuals in the energy transition process. By investigating the extent of public engagement and participation in energy transition initiatives, this study seeks to shed light on the factors influencing people's involvement. By exploring individuals' motivations, barriers, and decision-making processes, this research can provide valuable insights into strategies for effectively engaging and mobilizing the public in energy transition efforts. Understanding the level of public involvement is crucial for designing and implementing policies and initiatives that promote a successful energy transition.

3. Methodology

3.1. Database

To facilitate the renovation process, platforms like ©Solvari have been established to offer guidance and assistance to renovators. It provides a convenient platform for individuals to easily compare and assess cost estimates from do-it-yourself (DIY) companies operating within their local area. Using ©Solvari, users can access complimentary quotes from leading construction companies and installers across the Netherlands. It also offers a range of services, including personalized advice at no charge, facilitating a comparative analysis of various DIY companies, and providing free quotes that are tailored to meet the specific requirements of each user's project. Through these services, individuals can shorten the process of gathering information and making informed decisions regarding their construction and installation needs. The platform, accessible through Google searches or advertisements, collects data through user submissions. Participants input data into the system, providing ©Solvari with permission to identify suitable tradesmen and contractors. Two exceptions in the input data are surface area and construction year. These details are accessible through the 'Kadaster' platform, specifically the BAG Viewer, where users can view current home data online by searching for the address, city, or postcode. This information has been searched and added by ©Solvari to the database. External verification of the city and zip code is conducted to ensure accuracy, serving as a quality control measure. Data were collected from 10,001 respondents; however, many were recorded multiple times, and some were related to Belgium. Requests pertaining to Belgium were excluded, narrowing the focus to respondents from the Netherlands, resulting in 1114 recorded requests who accessed the ©Solvari platform in the Netherlands seeking various renovation services and advice. The questionnaire administered to these applicants consisted of several sections. Firstly, building characteristics such as the construction year and surface area were captured. Secondly, occupants' profiles, including their ownership status, were recorded. Additionally, regional factors, specifically the postal code of the houses, were included to examine potential regional variations. Lastly, respondents were asked to specify the type of renovation request, which could pertain to the building's exterior, interior, insulation, and installation aspects. The respondents' data included a wide range of house sizes, including small-sized, middle-sized, and large-sized houses, as well as different ownership situations. The study focused specifically on the responses related to energy-efficiency measures. The variables and database information are shown in Table 2. Before conducting the analysis, excluding data related to Belgium was necessary, justifying additional research into regional policies and programs specific to that area. Zip codes, represented by two digits, were systematically recorded and, in this study, are linked to each province. Furthermore, the provinces are further categorized into four distinct regions, facilitating the formulation of generalizable statements. The distribution of construction years within the dataset spans from older constructions to recently built ones, offering a comprehensive representation of the diverse buildings' characteristics. Moreover, the surface area ranges from small to large-scale buildings. Despite this diversity, a significant majority, accounting for 87.2 % of the buildings are below the 200 m2. Subsequently, requests have been categorized into two main groups: those on energy-related renovations (ESMs) and those related to other types of renovations. The specifics of this categorization are shown in Table 3. These responses were analyzed to identify patterns, trends, and preferences among renovators. Spatial analysis techniques were employed to understand the spatial distribution of interest in energy retrofitting. This involved analyzing the data collected from residents across various regions to identify geographical variations in interest and engagement in energy retrofitting initiatives. This study aims to identify the more influential factors on the ERI rate using this extensive dataset and employing spatial analysis techniques. The findings will contribute to developing targeted strategies and interventions to promote and accelerate energy transition efforts in the residential sector.

Table 1
ERI rate indicators as criteria for a household to be considered as a participant in energy-saving [5,7,15,27–29].

ERI rate indicators		
EER factors	Variants	
	EER strategies	ESMs
Building Envelope Insulation (BEI)	Thermal insulation (TI)	Roof insulation Floor insulation Façade insulation
	Windows (W)	Window and type of glass
Building Services (BS)	Heating system (HS)	Space heating system Domestic hot water system (DHW) Combi DHW and space heating
	Ventilation system (VS)	Ventilators
Building Installation (BI)	Renewable energy installation (REI)	Solar Panel

Table 2
Variables and database information.

Variables		
Location	The Netherlands	
Two digit Zip codes for the Netherlands	Region division base provinces Region NL1 (North Netherlands): Groningen, Friesland, Drenthe Region NL2 (East Netherlands): Overijssel, Gelderland, Flevoland Region NL3 (West Netherlands): Utrecht, North Holland, South Holland, Zeeland Region NL4 (South Netherlands): North Brabant, Limburg	
Year of construction	1750 - 2021	
The request for services	ESMs (95.4%)	See Table 3
	Others (4.6 %)	Chimney renovation facade cleaning Facade plastering Chimney cleaning Roof cleaning Composite cladding Placing or replacing plastic cladding facade cladding brick Sound isolation Maintain or repair air conditioning Cleaning solar panels Saving advice/ Insulation Saving advice Greening roof

3.2. *Methods of analysis*

The analysis of people's participation in energy-efficient renovations (EER) in this study was conducted from three distinct perspectives: building envelope insulation (BEI), building service (BS), and building installation (BI). Each perspective involves various variants and strategies, summarized in Table 1 according to the prior scholars' definitions [5,7,8,19,33,34]. The identified variants and strategies related to BEI include roof insulation, floor insulation, façade insulation, window types, and glass. In contrast, the BS perspective includes space heating systems, domestic hot water (DHW) systems, Combi DHW and space heating, and ventilators [5,7,33]. Solar panels were also considered an essential factor within the analysis under the category of renewable energy installation. The study categorized the different types of retrofitting service requests under the corresponding EER factors. The collected data was then analyzed using statistical software, including SPSS and MATLAB, employing descriptive statistics to understand the correlation between the ERI rate indicators and the EER factors. Additionally, Geographic Information Systems (GIS) tools were utilized to map and analyze the spatial distribution of interest in energy retrofitting. This allowed for a comprehensive understanding of the geographical variations in people's engagement with EER initiatives across different regions.

4. Results

In this section, the results of the descriptive and spatial analysis are presented. The data related to the source of information are analyzed regarding three ERI rate indicators and in response to the question, "Which factor plays a more significant role in motivating occupants to take action towards EER by providing the support and advice of the experts?". The database has included 1114 applicants in the Netherlands, and 1062 recorded requests were related to the EER. Generally, the findings related to the type of requests and services show that most registered requests relate to solar panel installation (Fig. 3). It aligns with the EU member statement that diverts attention from end-use consumption and emphasizes the transition to renewable energy

Table 3
The list of requests from the occupants.

The requested services from occupants			
Energy-Efficient Retrofitting (EER) components	EER-related strategies	Energy Saving Measure (ESM)	Energy Retrofitting Inquiries (ERI)
Building Envelope Insulation (BEI) (43.5 %)	Thermal Insulation (TI) (33.9 %)	ESM1 (8.9 %)	Pitched roof insulation (inside/outside) Insulate ceiling Flat roof insulation
		ESM2 (13 %)	Crawl space insulation / Increase crawl space
		ESM3 (12 %)	Cavity wall insulation Insulate exterior wall
	Windows (W) (9.7 %)	ESM4 (9.7 %)	Install or replace frames (wooden/ plastic/ aluminum) Dubbel glass / Glass insulation Install or replace plastic roof dormer Install or replace the skylight Change door glass with HR++ glass
Building Services (BS) (15,2%)	Heating System (HS) (12.5 %)	ESM5 (9.3 %)	Install or replace heat pump (air–water / ground-water / air to air/hybrid) Install or replace a solar water heater Heat pump water - water Install or replace electric underfloor heating Installing or replacing water-based underfloor heating Infrared heater Electric accumulators Pellet stove installation
		ESM6 (0.4 %)	Boiler / Heat pump boiler
		ESM7(2.9 %)	Maintain central heating boiler Install or replace central heating boiler (to buy/ to rent)
	Ventilation System (VS) (2.5 %)	ESM8 (2.5 %)	Central ventilation Maintain or clean ventilation
Building Installation (BI) (41.3 %)	Retrofit Installation (RI) (41.3 %)	ESM9 (41.3)	Install solar panels (private/commercial / to rent /) Deliver solar panels (DIY) Home battery

sources rather than prioritizing energy-efficient housing [35,36]. The list of requests from the occupants is in Table 3.

4.1. Source of information for characteristics of buildings and occupants' profiles

The statistical analysis shows that buildings were constructed between 1750 and 2021. Most applicants are owners (70.1 %) or will be owners within a few months. Fig. 4 shows, the most requests are for the houses that were built between 1950 and 1990. It can be interpreted that the house at the age of 33 has the most requests for energy retrofitting and is mainly related to the building insulation (Table 4). The results reveal a significant correlation between building age and occupant concern for energy renovation. The Correlation between BEI and construction years is −0.89, the correlation between BS and construction years is −0.83, and the correlation between BI and construction years is −0.77. These correlation coefficients indicate a negative relationship between the construction years and the percentages of these building strategies. This implies that newer construction years tend to have lower rates of these building strategies, while older construction years tend to have higher percentages (Fig. 4). Therefore, it can be concluded that occupants of houses constructed over 30 years ago expressed a higher level of interest in energy renovation, driven by the age-related issues of outdated systems, poor house conditions, and high energy bills. In contrast, occupants of newly built houses are likely to tend to overlook maintenance and monitoring, probably due to unfamiliarity with the technologies incorporated into these buildings.

Regarding surface area size, the results show that the middle-sized houses have the most requests for EER (Fig. 5). The correlation between surface area and BEI is −0.14, the correlation between surface area and BS is 0.07, and the correlation between surface area and BI is 0.02. In summary, the correlations indicate a weak negative relationship between the surface area and BEI, a weak positive relationship between the surface area and BS, and almost no relationship between the surface area and BI (Fig. 6). It can be concluded that occupants' income has no connection with the ERI rate.

4.2. Source of information for spatial analysis

This study examines the ERI rate across different postcodes in the Netherlands to consider different regional effective factors. A province-level analysis of the ERI rate throughout the country is conducted by linking each postcode with its corresponding province (Figs. 7-10). The findings revealed significant variations in ERI rates across provinces, with South Holland (17.30 %) and North Holland (14.60 %) showing the highest rates. Conversely, Flevoland (2.9 %) and Friesland (3 %) had the lowest ERI rates. The map presented in Fig. 11 illustrates these disparities, employing a color-coded scheme to represent different ERI rates, ranging from high (17.39 %) to low (2.99 %), across the Netherlands. Remarkably, the results indicate that households in the Randstad area, which comprises major urban centers, express more significant concerns about EER than other regions in the country. This observation aligns with the trend of urban renovation projects primarily focusing on the Randstad area in recent decades. At the same time, less densely populated regions in the north and east of the country have seen fewer renovations [28]. This discrepancy may be attributed, at least in part, to the higher population density in the Randstad area, leading to increased awareness and exposure to EER strategies, incentives, and expert support among its residents. Specifically, the BEI rate is high in North Holland, while the BS rate is high in South Holland. Additionally, the analysis involved dividing the Netherlands into four regions: Region NL1 (North Netherlands: Groningen, Friesland, Drenthe provinces), Region NL2 (East Netherlands: Overijssel, Gelderland, Flevoland provinces), Region NL3 (West Netherlands: Utrecht, North Holland, South Holland, Zeeland provinces), and Region NL4 (South Netherlands: North Brabant, Limburg provinces) (Fig. 12). Fig. 13 demonstrates the ERI rates within each region, highlighting that Region NL3 (43 %) showed the highest ERI rate among the four regions.

Overall, the geographical distribution of ERI rates in the Netherlands emphasizes higher concern and participation in the South Holland and North Holland provinces. These findings shed light on the impact of population density and the implementation of urban renovation projects on household awareness and engagement with EER initiatives.

4.3. Correlation between the EER factors and ERI rate

This model considers the impact of four factors, including construction year, surface area, ownership, and region in ERI rate. It shows that a correlation is significant at the 0.001 level. It means that there is a highly statistically significant relationship between the variables. When interpreting the model, it can be concluded that the relationship between the analyzed variables is solid and reliable. The standardized

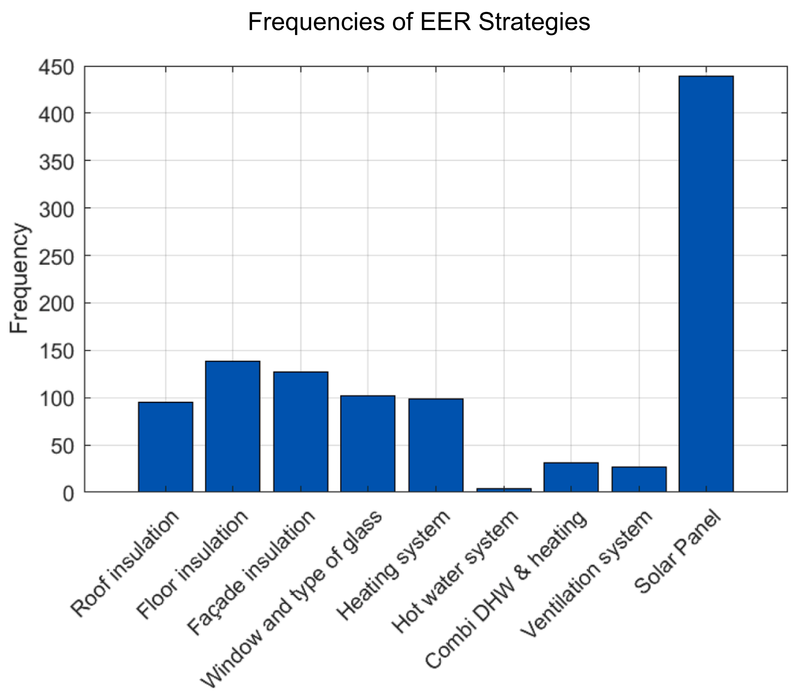

Fig. 3. Frequencies of EER Strategies requested by individuals.

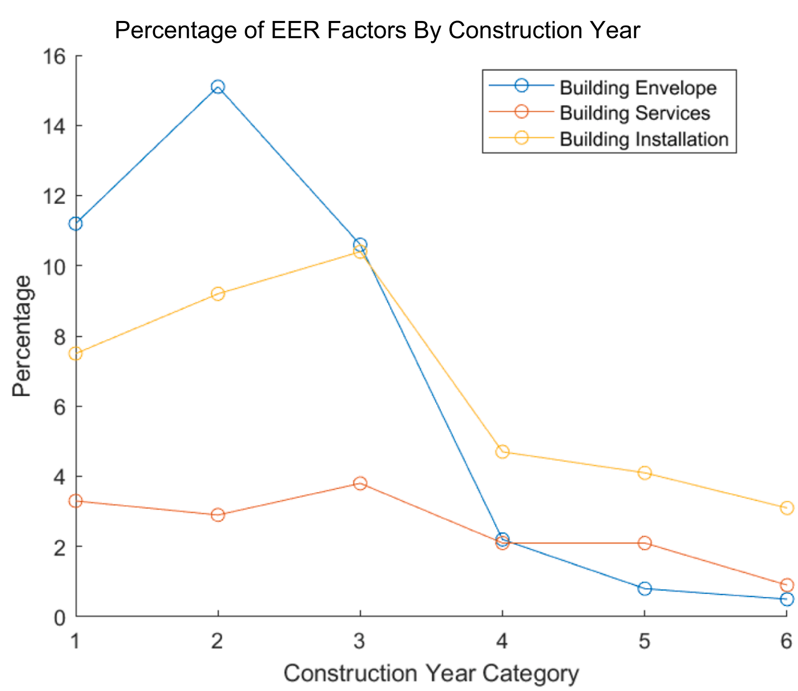

Fig. 4. The rate of ERI according to the construction rate.

coefficient and significance level suggest a strong and statistically significant negative relationship between the region and ERI rates. It reveals that higher postal code values in each region variable are linked with a lower rate of the ERI. It means that the north and south of the Netherlands have a low rate of ERI. For construction, the year indicates a moderate and highly significant positive relationship between the variables being analyzed. This shows that the construction year variable has a statistically significant positive impact on the ERI rate, suggesting that a higher year of construction leads to a higher rate of the ERI. For surface area, the standardized coefficient with a significance level indicates a fragile and non-significant relationship between the variables being analyzed. The small magnitude of the coefficient suggests a negligible impact of the surface area variable on the ERI rate variable. The significance level (sig.) of 0.672 means that the observed relationship between the variables is not statistically significant and does not provide strong evidence to support a meaningful relationship between the variables. It can be interpreted that the size of the buildings, which is related to the occupants' profile, such as affordability of the households

Table 4
The rate of ERI according to the building characteristics.

EER factors	Construction Year						Area		
	(1)	(2)	(3)	(4)	(5)	(6)			
	<1950	1950–1975	1975–1990	1990–2000	2000–2010	>2010	<100	100–200	>200
	%						(m^2)		
Building Envelope Insulation (BEI)	11.20	15.10	10.60	2.20	0.80	0.50	7.50	28.50	3.70
Building Services (BS)	3.30	2.90	3.80	2.10	2.10	0.90	2.10	10.00	2.70
Building Installation (BI)	7.50	9.20	10.40	4.70	4.10	3.10	5.40	27.00	5.90
Total ERI rate	22.00	27.20	24.80	9.00	7.00	4.50	15.00	65.50	12.30

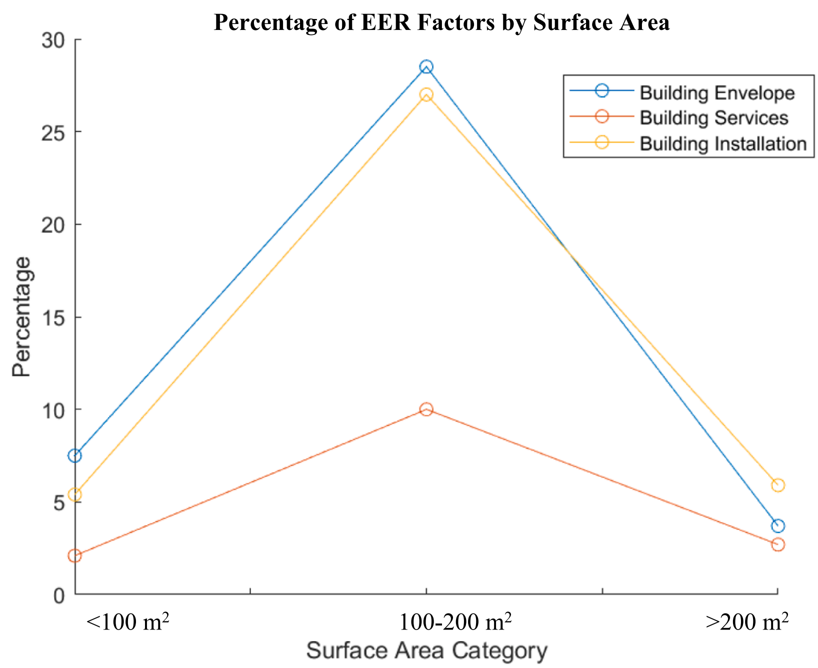

Fig. 5. Correlation between EER factors and surface area size.

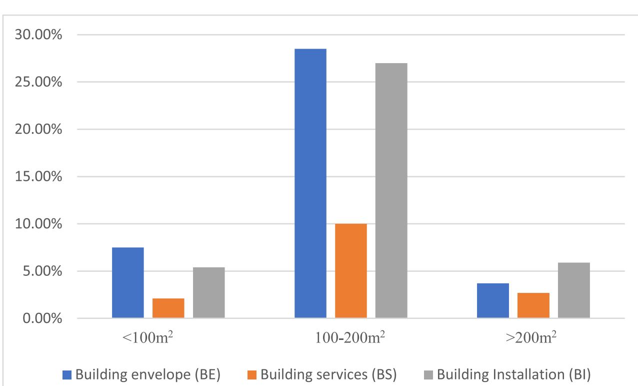

Fig. 6. ERI rate based on the surface area size.

or number of family members, does not play an essential role in occupant participation in EER. For ownership, the standardized coefficient and the significance level indicate a small but statistically significant positive relationship between the variables. This suggests that as the number of owners increases, there is a corresponding increase in the rate of the ERI.

Table 5 shows the relationship between each EER factor and the independent variables. A positive relationship exists between the region and the dependent variable for BEI and BS. At the same time, there is a negative relationship between ownership, year of construction, surface area, and the BEI and BS rates. It means that if an owner occupies the building, by increasing the size and construction year of the buildings, the request for BEI and BS will be increased. Also, this request is more related to the people living in the NL3 zone. For BI, there is a positive relationship between the region, surface area, and the dependent variable. At the same time, there is a negative relationship between ownership, year of construction, and the BI rates. It can be interpreted that middle-sized houses are concerned about installing solar panels, and it is not limited to one region, construction year, or ownership. Therefore, BI is more inclusive and does not contribute to energy saving, so people are thinking more about harvesting energy. It necessitates policy regarding the energy consumption of the households).

Hence, the model shows that four factors influence the ERI rate. In summary, the construction year factor with a significance level of < 0.001 has the most impact as it indicates a statistically significant relationship between the variables. The factors with higher significance levels (0.012, 0.672, and 0.023) suggest statistically substantial relationships with increasing chances of the relationships being due to random chance. Therefore, it can be concluded that the construction year and the characteristics of the building have the most impact on the rate of ERI (Table 6).

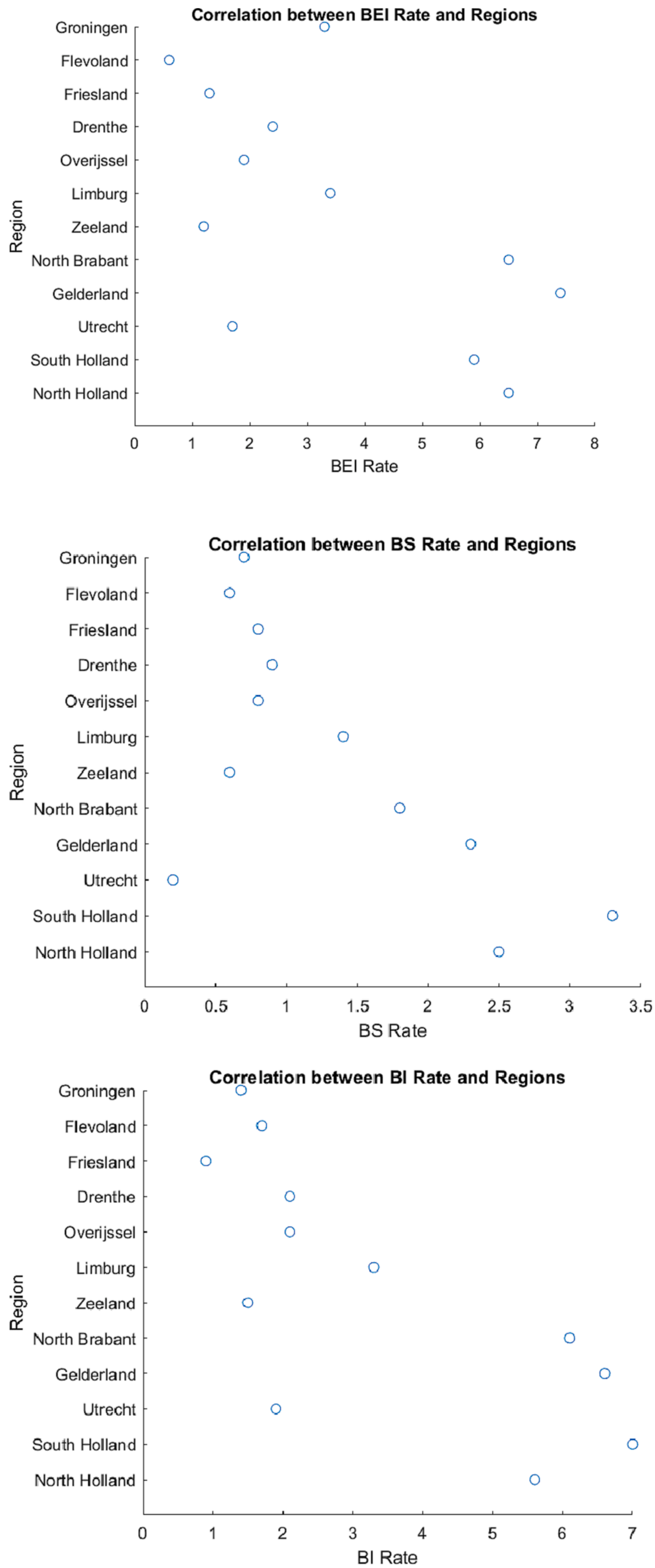

Fig. 7. Correlation between EER factors and the provinces.

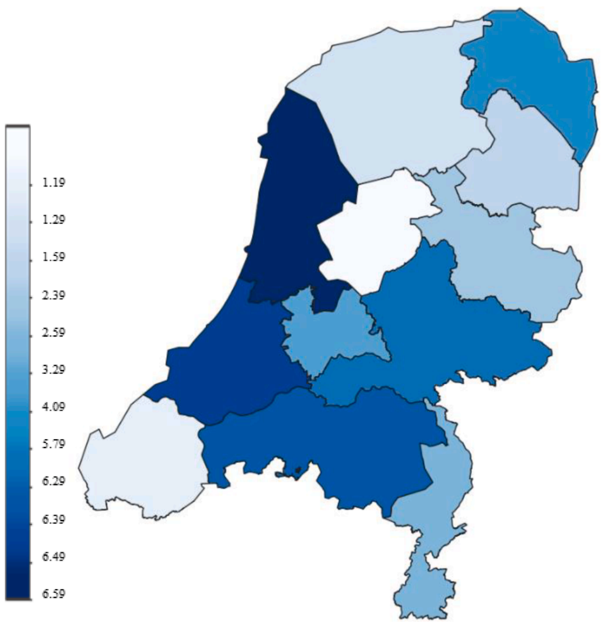

Fig. 8. BEI rate in each province.

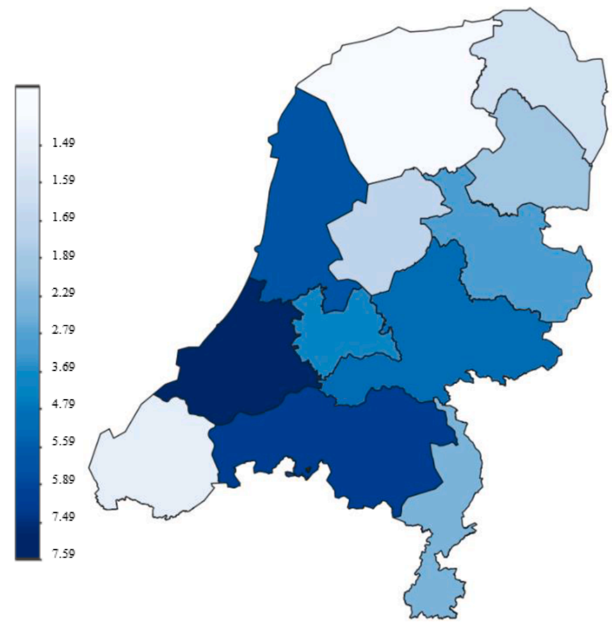

Fig. 10. BI rate in each province.

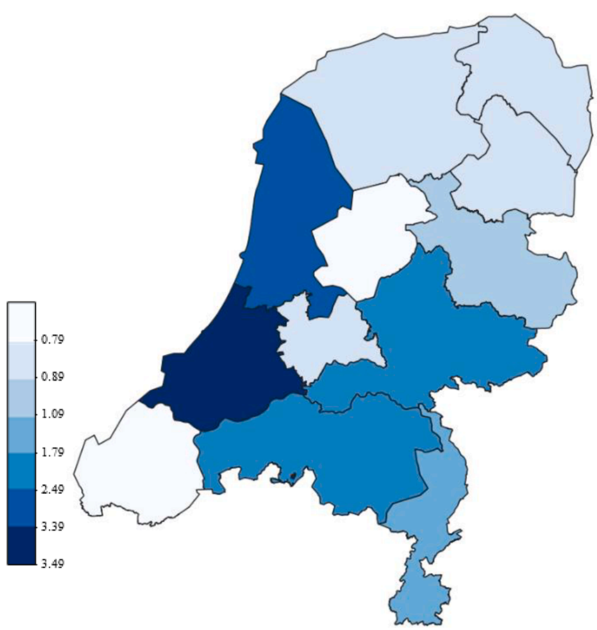

Fig. 9. BS rate in each region.

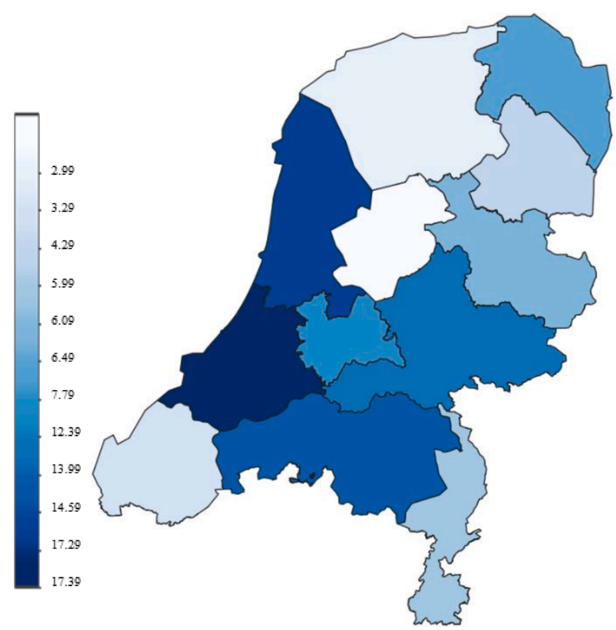

Fig. 11. ERI rate per province in the Netherlands.

5. Discussion

To address the challenges renovators face in determining the most effective approaches for energy-efficient renovations, the engagement of experts becomes crucial. These experts can provide valuable support and advice throughout the renovation process. Construction stores/DIY companies and maintenance/installation companies serve as the primary sources of information for EER practices [19]. This study used the database provided by ©Solvari platform to explore the occupants' inquiries for energy retrofitting and determine which factors related to the building characteristics, occupants' profiles or policies, and incentives significantly impact the ERI rate. These factors include region, construction year, surface area, and ownership. The impact of these factors are discussed in the following sections.

5.1. Impact of building characteristics and occupants on ERI

The results related to the relationship between building age and occupant concern for energy renovation show the necessity of implications for maintenance and education in newly constructed buildings. This study examines the correlation between building age and occupant concern for energy renovation. The results indicate that occupants of houses built over 30 years ago show a greater inclination towards energy renovation. The aging systems, and the house's condition and energy bills, motivate occupants to consider retrofitting. Conversely, occupants of recently built homes tend to overlook system maintenance and monitoring. Educating occupants on interacting with the new technologies integrated into these buildings is crucial to enhancing system durability and performance. Regular monitoring is recommended to keep occupants informed and engaged. As buildings age, their systems

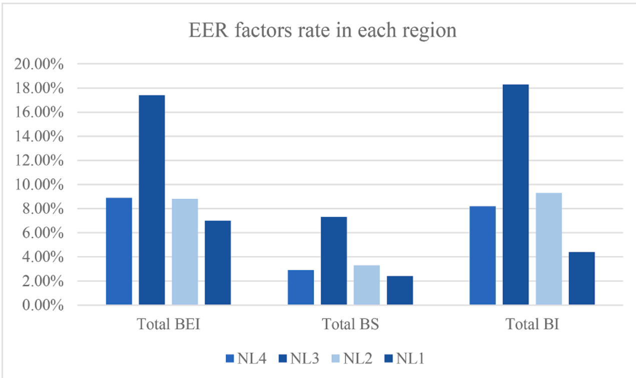

Fig. 12. BEI, BS, BI rate in each region.

often deteriorate, leading to increasing energy consumption and higher utility bills. In contrast, newly constructed buildings offer advanced technologies and improved energy efficiency. However, occupants of such buildings may lack awareness and understanding of these systems, leading to neglect of maintenance and monitoring. This research emphasizes educating occupants in newly built buildings to ensure energy systems' long-term performance and sustainability. The findings highlight the need for education and awareness programs targeted toward occupants of newly constructed buildings. By equipping them with knowledge about system maintenance and monitoring, occupants can actively contribute to optimizing energy efficiency and prolonging the lifespan of the systems. Regular monitoring initiatives, such as informative newsletters or online platforms, can serve as practical tools to engage and inform occupants.

It is expected that low-energy buildings, with substantial dependence on passive design and complicated technologies, need to meet design goals due to operational behavior [37,38]. For example, the underperformance of mechanical ventilation and heat recovery systems, as well as air source heat pumps, can be attributed to inadequate commissioning and maintenance procedures, and challenges in occupant control due to complex control interfaces [39]. Therefore, a radical change in how individuals use energy in their lifestyle is crucial [40]. Knowledge, communication, and engagement are essential for individuals to alter their lifestyle toward a more environmentally friendly lifestyle [41]. This combines the supply of accurate information and the

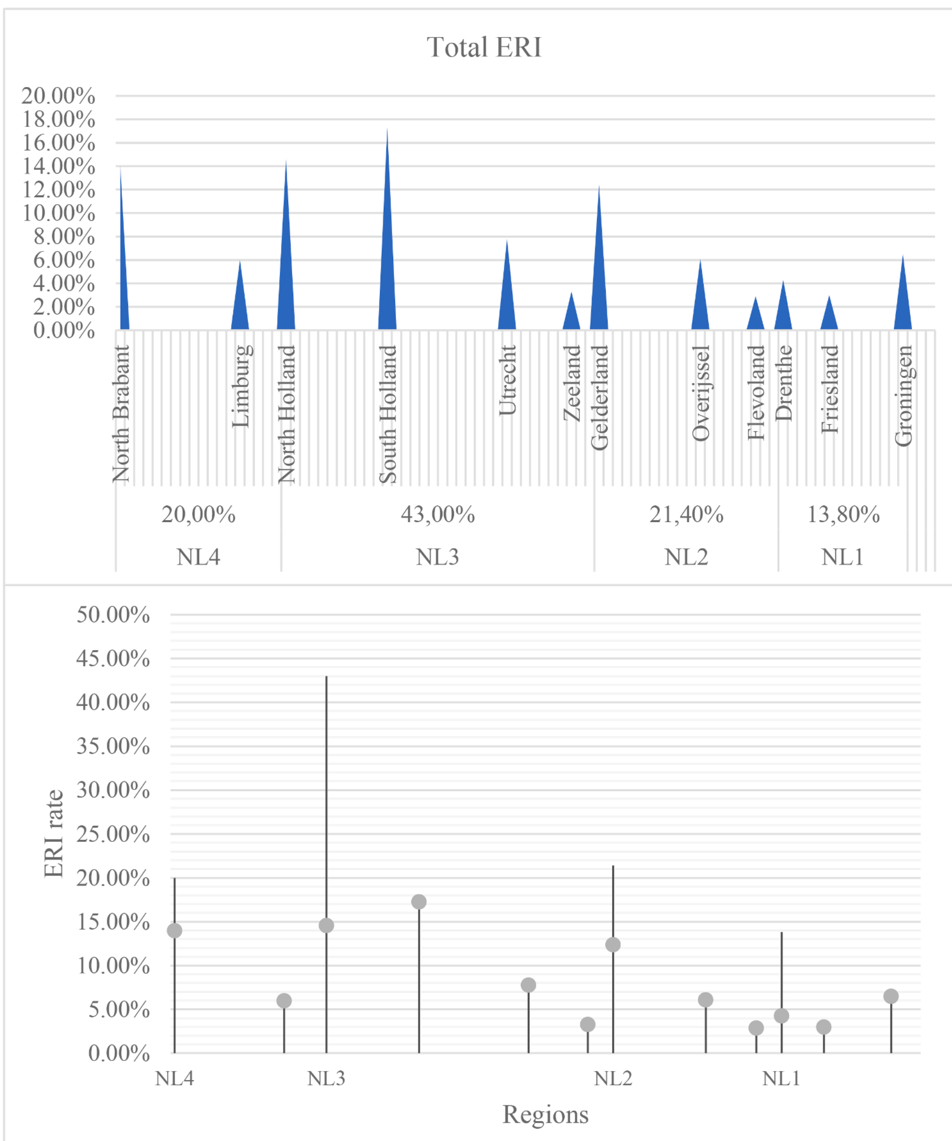

Fig. 13. Total ERI rate in each provinces and regions.

Table 5
Relationship between EER factors and independent variables - Linear regression results.

Dependent Variable	Independent Variable	Std. Error	Standardized Coefficients	t	Sig.
BEI	Region	2.347	0.396	0.609	0.604
	Construction year	0.780	−0.887	−3.838	0.018
	Surface area	2.511	−0.386	−0.418	0.748
	Ownership	101.614	−0.868	−1.752	0.330
BS	Region	1.168	0.316	0.471	0.684
	Construction year	0.154	−0.831	−2.982	0.041
	Surface area	10.248	−0.073	−0.073	0.953
	Ownership	22.517	−0.890	−1.954	0.301
BI	Region	2.884	0.447	0.707	0.553
	Construction year	0.502	−0.774	−2.447	0.071
	Surface area	1.212	0.672	0.907	0.531
	Ownership	79.097	−0.872	−1.783	0.325

Table 6
Potential drivers of EER- Linear Regression.

Model			Standardized Coefficients	t	Sig.
		Std. Error	Beta		
1	Region	0.001	−0.094	−2.574	0.010
2	Region	0.001	−0.090	−2.491	0.013
	Construction_year	0.001	0.184	5.098	<0.001
3	Region	0.001	−0.090	−2.487	0.013
	Construction_year	0.001	0.183	5.071	<0.001
	Surface	0.000	0.014	0.390	0.696
4	Region	0.001	−0.091	−2.522	0.012
	Construction_year	0.001	0.179	4.948	<0.001
	Surface	0.000	0.015	0.424	0.672
	Ownership	0.178	0.082	2.284	0.023

a. Dependent Variable: ERI Factors

promotion of efficient energy consumption with the benefits to individuals' lives and the environment [42]. Occupant behavior after renovation is critical to achieving energy efficiency objectives [43]. Many existing studies reviews have focused on technological improvements, which did not lead to a lifestyle change rather than behavioral parameters [40]. Therefore, it is suggested that the occupants' perception of energy, control, or comfort has to be considered during energy efficiency retrofits [44]. It can refer to the occupants' behaviors in deciding to renovate the buildings or after the renovation.

Additionally, the analysis shows that occupants are interested in installing solar panel systems. Therefore, they need to be educated and aware of how to monitor, clean, or maintain the system. Moreover, occupants have been encouraged to improve the insulation level of the buildings. Thus, it is necessary to be aware of the system's ventilation to avoid any building-related illness due to installing HVAC systems [45], air-tight systems, and more thermally insulated houses [46]. As Fig. 14 shows, the occupants who apply to install new energy-efficient systems, solar panels, or insulation in the house, need to get advice before renovation, participate during the implementation, and be monitored after renovation. As the findings show, renovators prioritize the comfort level over the maintenance of energy-saving measures (ESMs) [19]. It should start with the issues that affect them locally [47,48]. The suggestion is to increase the tendency of the occupants to be involved in the maintenance of the energy system. In terms of the design of the technologies, instead of being maintenance-free systems, the designs can be attractive and pleasant to take care of [43]. Probably, the awareness raising of energy use can be achieved by designing objects of daily use in a playfully challenging way [43]. Informing residents through a more image-based manual, responsible innovation responsive to the residents [49], and an integral approach to a sustainable renovation involving residents is needed [43]. Since people use them differently than expected or do not take care of them well, there is often a tendency to make things as fully automatic and maintenance-free as possible and avoid any user involvement. No process framework currently exists that integrates resident participation with the renovation process. Design participation is a social design approach that seeks to support collaboration between the residents and the other stakeholders with design tools. Overall, the examples reveal that there are still gaps between design participation thinking and the current participation and innovation processes in this field. Many recent publications have suggested that an integral approach involving residents is needed in sustainable

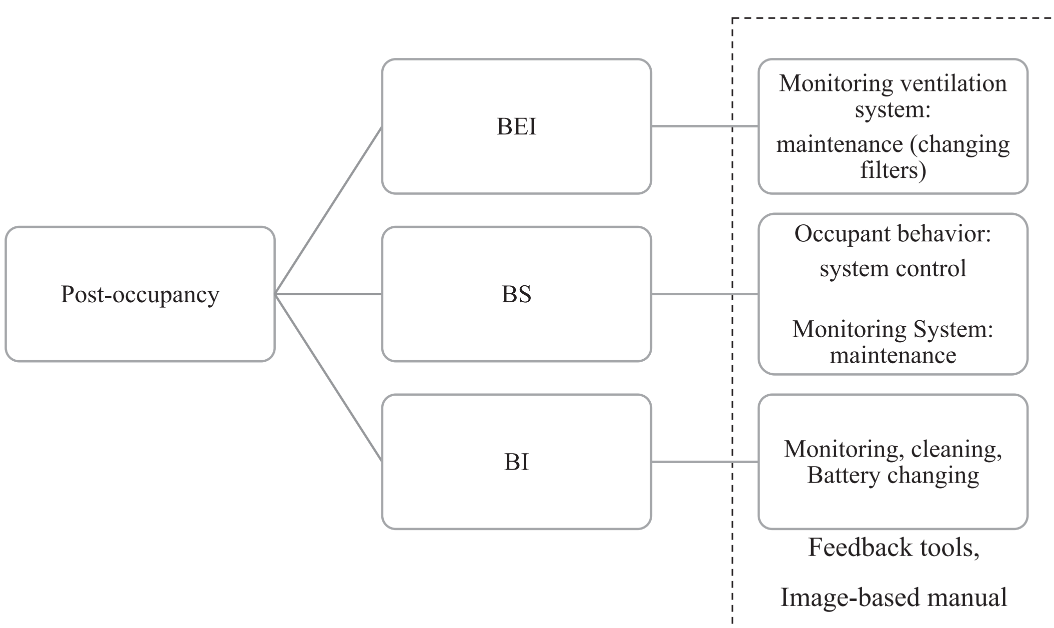

Fig. 14. Post-occupancy consideration factors.

renovation [43]. Moreover, a monitoring system [23], feedback loops, and a more image-based manual [32] are necessary at the post-occupancy stage. As aforementioned, insufficient commissioning and maintenance procedures, and inadequate occupant control, contribute to the underperformance of mechanical ventilation, heat recovery systems, and air source heat pumps [39]. Therefore, behavioral control is essential to achieve the goal of energy-efficient retrofitting in buildings.

Exploring the influence of house size on energy retrofitting necessitates implications for small-size houses, low-income individuals, and tenants in the energy transition. This study investigates the relationship between house size and the motivation for energy retrofitting. The findings reveal that middle-sized houses are more inclined toward energy retrofitting than small-sized houses. However, small-sized houses, low-income individuals, and tenants show limited interest in the energy transition. This group may need help with barriers that hinder their engagement in energy transition activities. The paper emphasizes the critical role of policy interventions in providing targeted subsidies to address the challenges faced by these groups, enabling their active participation in energy retrofitting initiatives and fostering energy efficiency improvements in their dwellings. Targeted subsidies can help mitigate the financial constraints associated with energy retrofitting, making it more accessible and appealing. Additionally, awareness campaigns and educational initiatives tailored to these groups can help overcome the knowledge gap and foster engagement in energy retrofitting activities. Targeted awareness campaigns and appeals to environmental responsibility could have direct (energy-saving practices) and indirect effects (adoption of energy-efficient appliances) on households' behaviors [50]. Moreover, the expert's support and advice, information sources, and instructions for maintenance and installation are influential factors in energy efficiency renovation concerning the occupants' participation [7,19]. However, awareness alone does not always translate into behavior change [51].

5.2. Impact of regional policies on ERI

Spatial analysis of interest in energy retrofitting in different regions of the Netherlands shows that South Holland and North Holland are exemplary regions and have implications for addressing EER in other areas. The findings indicate that individuals residing in the West Netherlands are more interested in energy retrofitting initiatives. Compared to Mulder et al.'s study on energy poverty [28], it becomes evident that this region demonstrates a relatively low prevalence of tenants, low-income occupants, and houses with low energy quality and is not significantly affected by energy poverty. Rural areas appear to experience a higher prevalence and greater severity of energy poverty than urban areas [52].

This interest can be attributed to various factors, such as awareness, socioeconomic conditions, and access to different resources. Generally, effective policy interventions, financial incentives, and educational campaigns are necessary to address the barriers faced by each region to promote energy retrofitting practices. Hence, the paper sheds light on regional disparities and identifies areas requiring government intervention and targeted actions to address EER effectively. In light of the conclusion, there is a possibility of higher usage of this platform in the NL3 region compared to other regions, indicating potential variations in platform preferences across different regions. Consequently, it is not appropriate to generalize the observed outcomes to all regions, as it is reasonable that regional policies and practices may differ. When considering the application of the energy retrofitting indicators developed in the Netherlands to other countries or geographical areas, it is crucial to recognize that direct implementation requires an adaptable approach. Local conditions, regulations, and cultural contexts vary significantly, emphasizing the need for careful consideration and customization. Collaborative efforts and the exchange of best practices play a vital role in the success of global energy retrofitting initiatives. Adapting these indicators globally involves addressing diverse factors such as local regulations and standards, climatic conditions, building types and materials, economic considerations, technology availability, socio-cultural factors, and data availability. Engaging with local stakeholders, experts, and policymakers is essential for effective implementation. In large-scale energy retrofitting for buildings, a key challenge is categorizing each housing type based on the required extent of demand reduction [53]. Hence, a primary consideration is the availability of building data, which forms the foundation for informed decision-making. Addressing energy retrofitting indicators such as insulation, it becomes evident that the Netherlands' climatic conditions necessitate building insulation and corresponding ventilation systems. This indicator reflects people's participation and awareness regarding insulating envelopes in countries with comparable conditions. Establishing platforms and campaigns for public awareness, policies, and subsidies becomes essential for this energy retrofitting practice. Regarding building services, the Netherlands predominantly requires heating systems. For regions with similar climatic conditions, adapting to new energy retrofitting technologies, and effective monitoring and maintenance is recommended. Regarding energy-related technologies installation, the popularity of installing photovoltaic systems in the Netherlands, regarding the country's lower number of sunny days and driven by energy prices, highlights a significant indicator. Government and municipal support, particularly through subsidies, is crucial to promote similar initiatives globally.

The study of Escandón et al. [54] shows that any energy retrofitting practices should prioritize actual user profiles over standardized ones. Moreover, a more thorough economic examination of energy savings and investments in the context is required. Additionally, the energy retrofitting of the building stock carries social implications, requiring resident involvement and acceptance of proposed interventions. Lastly, examining the political barriers to self-consumption and energy production is crucial for planning strategies that can enhance retrofitting rates and align with European decarbonization objectives. It can be concluded that the energy retrofitting strategy holds the potential for implementation in diverse climates, especially with modifications in the facade operation [54]. In summary, the worldwide successful application of energy retrofitting indicators from the Netherlands requires an inclusive approach that considers and integrates local factors and collaborations.

6. Conclusion

This study investigated the occupants' inquiries rate in EER. An analysis of occupants of the Netherlands has been conducted based on the source of information of 1062 applications. The study demonstrates that occupants of houses constructed over 30 years ago show a deeper concern for energy renovation, driven by the necessity to address aging systems and improve energy efficiency. Conversely, occupants of recently built houses tend to neglect system maintenance and monitoring, necessitating educational efforts to enhance their understanding of the integrated technologies. Regular monitoring initiatives are recommended to keep occupants informed and engaged, fostering a culture of energy-conscious behavior in newly built buildings. The study highlights the influence of house size on the motivation for energy retrofitting. While middle-sized houses show higher enthusiasm, small-sized houses, low-income individuals, and tenants face distinct challenges in participating due to various factors. In summary, this article explores occupant inquiries regarding energy retrofitting approaches and identifies a greater emphasis on building insulation and installation than building services. Two critical reflections emerge: 1) Policies, incentives, and subsidies predominantly focus on these two practices; 2) There is a considerable awareness gap concerning building services. This suggests that the upgrading, monitoring, and maintenance of building services may be overlooked by the occupants. Consequently, initiatives are needed to be explored to address this aspect. Policy interventions are crucial in addressing these barriers by offering targeted subsidies and implementing tailored educational campaigns. By doing so, energy retrofitting efforts can be extended to include a broader range of houses and populations, promoting a more inclusive and sustainable energy transition. The spatial analysis highlights the NL3 region as a frontrunner in terms of interest in energy retrofitting. However, other regions may use other platforms and have different targeted actions from the government to increase the ERI rate effectively. Policymakers should implement region-specific strategies, including financial incentives, awareness campaigns, and policy interventions, to promote energy retrofitting and alleviate EER in those regions. This can be accomplished according to each municipality's requirement, considering the individuals, their needs and awareness, the housing conditions, the appropriate energy retrofitting strategies, and the type of support. Developing specific programs, incentives, or regulations tailored to their local context and the needs of their communities can be followed by these steps:

(1) Conduct a local needs assessment, identify and understand the local community's ERI, and evaluate local and available financial and technical resources within the local community.
(2) Engage with stakeholders, and collaborate with energy community members, businesses, and organizations to gather diverse perspectives, and understand the priorities and preferences of local stakeholder groups.
(3) Customize programs and incentives (ensure alignment with broader regional, national, or international energy and environmental goals) that match the preferences and motivations of the local population and address specific local needs and community resilience.
(4) Consider cultural and social factors that may influence the acceptance and success of programs, and ensure that programs are inclusive and accessible to all segments of the community, including vulnerable groups, and encourage community participation in decision-making processes.
(5) Develop educational campaigns to raise awareness about EER strategies and the benefits of proposed programs within the community, monitor and evaluate program effectiveness, and use feedback and data to make informed adjustments and improvements over time.

To contribute further to this field of research, investigating additional factors influencing occupants' energy-related decisions and exploring novel approaches to enhance occupants' awareness and active involvement in EER is suggested. Adapting the energy retrofitting indicators used in the Netherlands and their application to other countries or regions necessitates thorough consideration and adjustment to local conditions, regulations, and cultural contexts. Successful global energy retrofitting initiatives can be facilitated through collaborative endeavors and the exchange of best practices.

CRediT authorship contribution statement

Elham Maghsoudi Nia: Formal analysis, Methodology, Software, Visualization, Writing – original draft, Data curation. **Queena K. Qian:** Conceptualization, Data curation, Supervision, Writing – review & editing. **Henk J. Visscher:** Supervision.

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

The data that has been used is confidential.

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References

[1] S. Ebrahimigharehbaghi, et al., Unravelling Dutch homeowners' behaviour towards energy efficiency renovations: What drives and hinders their decision-making? Energy Policy 129 (2019) 546–561.
[2] H. Van Der Bent, et al., The energy performance of dwellings of non-profit housing associations in the Netherlands 2017–2018. IOP Conference Series: Earth and Environmental Science, IOP Publishing, 2019.
[3] Netherlands, G.o.t. *Measures to reduce greenhouse gas emissions*. 2017; Available from: https://www.government.nl/topics/climate-change/national-measures.
[4] R.P. van Leeuwen, J. De Wit, G.J.M. Smit, Review of urban energy transition in the Netherlands and the role of smart energy management, Energ. Conver. Manage. 150 (2017) 941–948.
[5] F. Filippidou, N. Nieboer, H. Visscher, Effectiveness of energy renovations: a reassessment based on actual consumption savings, Energ. Effi. 12 (1) (2019) 19–35.
[6] Konstantinou, T., et al. *An integrated design process for a zero-energy refurbishment prototype for post-war residential buildings in the Netherlands*. in *SASBE 2015: Proceedings of the 5th CIB International Conference on Smart and Sustainable Built Environments*. 2015. Pretoria, South Africa: CIB (IInternational Council for Research and Innovation in Building and Construction).
[7] P. van den Brom, A. Meijer, H. Visscher, Actual energy saving effects of thermal renovations in dwellings—longitudinal data analysis including building and occupant characteristics, Energ. Buildings 182 (2019) 251–263.
[8] Energie, W., *Saving energy in the housing stock: insights from the Energy Module Woon 2018 (Energie besparen in de woningvoorraad: inzichten uit de Energiemodule WoON 2018)* A. Research, Editor. 2019: Delft, Netherlands.
[9] Nederland, R.v.O. *Energy label homes*. 2023 [cited 2024; Available from: https://www.rvo.nl/onderwerpen/wetten-en-regels-gebouwen/energielabel-woningen.
[10] BuildingLabel. *Woningbouw*. 2024; Available from: https://buildinglabel.com/.
[11] Ebrahimigharehbaghi, S., et al. *Analysing the energy efficiency renovation rates in the Dutch residential sector*. in *E3S Web of Conferences*. 2019. EDP Sciences.
[12] J. Laustsen, et al., Europe's Buildings under the Microscope, Buildings Performance Institute Europe (BPIE):, Brussels, Belgium, 2011.
[13] L. Jia, et al., Exploring key risks of energy retrofit of residential buildings in China with transaction cost considerations, J. Clean. Prod. 293 (2021) 126099.
[14] E. Cozijnsen, et al., Tevreden bewoners, Energiesprong, 2015.
[15] J.W. Bleyl, et al., Office building deep energy retrofit: Life cycle cost benefit analyses using cash flow analysis and multiple benefits on project level, Energ. Effi. 12 (1) (2019) 261–279.
[16] C. Wilson, L. Crane, G. Chryssochoidis, Why do homeowners renovate energy efficiently? Contrasting perspectives and implications for policy, Energy Res. Soc. Sci. 7 (2015) 12–22.
[17] B. Risholt, T. Berker, Success for energy efficient renovation of dwellings—Learning from private homeowners, Energy Policy 61 (2013) 1022–1030.
[18] C. Wilson, H. Dowlatabadi, Models of decision making and residential energy use, Annu. Rev. Env. Resour. 32 (2007) 169–203.
[19] S. Ebrahimigharehbaghi, et al., Transaction costs as a barrier in the renovation decision-making process: A study of homeowners in the Netherlands, Energ. Buildings 215 (2020) 109849.
[20] Sijpheer, N., et al. *Resultaten uit monitoring over: Tevreden bewoners*. 2015; Available from: http://energieling.nl/resources/resultatenmonitoringbewoners.
[21] R. Galvin, Making the 'rebound effect'more useful for performance evaluation of thermal retrofits of existing homes, Energ. Buildings 69 (2014) 515–524.
[22] L.F. Chiu, et al., A socio-technical approach to post-occupancy evaluation: interactive adaptability in domestic retrofit, Build. Res. Inf. 42 (5) (2014) 574–590.
[23] RVO. 2015 Available from: www.rvo.nl.
[24] Dolšak, J.J.E. and Buildings, *Determinants of energy efficient retrofits in residential sector: a comprehensive analysis.* 2023: p. 112801.
[25] 6, I., *Climate Change 2022: Mitigation of Climate Change*. 2022.
[26] C. Wilson, H. Dowlatabadi, Models of decision making and residential energy use, Annu. Rev. Environ. Resour. 32 (2007) 169–203.
[27] Mckenzie, B. *Incentives for Green Retrofit*. 2024 [cited 2024; Available from: https://resourcehub.bakermckenzie.com/en/resources/global-sustainable-buildings-index/europe-middle-east-and-africa/netherlands/topics/incentives-for-green-retrofit.
[28] P. Mulder, F. Dalla Longa, K. Straver, Energy poverty in the Netherlands at the national and local level: A multi-dimensional spatial analysis, Energy Res. Soc. Sci. 96 (2023) 102892.
[29] Diran, D., M. Hoekstra, and A.F. van Veenstra. *Applications of Data-Driven Policymaking in the Local Energy Transition: A Multiple-case Study in the Netherlands*. in *Electronic Participation: 14th IFIP WG 8.5 International Conference, ePart 2022, Linköping, Sweden, September 6–8, 2022, Proceedings*. 2023. Springer.
[30] Netherlands, G.o.t. *Climate policy*. 2024 [cited 2024; Available from: https://www.government.nl/topics/climate-change/climate-policy#:~:text=To%20combat%20climate%20change%2C%20the,a%2095%25%20reduction%20by%202050.

[31] Agency, P.N.E.A. *Climate target 2030 requires vigorous implementation of existing and new policy*. 2021 [cited 2024; Available from: https://www.pbl.nl/en/news/2021/climate-target-2030-requires-vigorous-implementation-of-existing-and-new-policy.
[32] RES), T.N.R.E.S.P.N. *Why have a Regional Energy Strategy(RES)?* 2023 8 July 2023]; Available from: https://www.regionale-energiestrategie.nl/english/default.aspx.
[33] Z. Zhou, et al., Achieving energy efficient buildings via retrofitting of existing buildings: a case study, J. Clean. Prod. 112 (2016) 3605–3615.
[34] Q. Li, et al., Optimizing energy efficiency and thermal comfort in building green retrofit, Energy 237 (2021) 121509.
[35] T. Dunlop, T.J.E.R. Völker, S. Science, The Politics of Measurement and the Case of Energy Efficiency Policy in the European Union. 96 (2023) 102918.
[36] Commission, E., *Impact Assessment—Accompanying the Document Proposal for a Directive of the European Parliament and of the Council amending Directive 2012/27/EU on Energy Efficiency*, in *COM (2016) 761 final, SWD (2016) 406 final, PART 1/3*. 2016: Brussels.
[37] J.K. Day, D.E. Gunderson, Understanding high performance buildings: The link between occupant knowledge of passive design systems, corresponding behaviors, occupant comfort and environmental satisfaction, Build. Environ. 84 (2015) 114–124.
[38] E. Rodriguez-Ubinas, et al., Energy efficiency evaluation of zero energy houses, Energ. Buildings 83 (2014) 23–35.
[39] M. Ortiz, L. Itard, P.M. Bluyssen, Indoor environmental quality related risk factors with energy-efficient retrofitting of housing: A literature review, Energ. Buildings 221 (2020) 110102.
[40] P. Gyberg, J. Palm, Influencing households' energy behaviour—how is this done and on what premises? Energy Policy 37 (7) (2009) 2807–2813.
[41] B. Mills, J. Schleich, Residential energy-efficient technology adoption, energy conservation, knowledge, and attitudes: An analysis of European countries, Energy Policy 49 (2012) 616–628.
[42] M. Pothitou, et al., A framework for targeting household energy savings through habitual behavioural change, Int. J. Sustain. Energ. 35 (7) (2016) 686–700.
[43] S. Boess, Design participation in sustainable renovation and living, in: Living Labs, Springer, 2017, pp. 205–226.
[44] E.M. Nia, Q. Qian, H. Visscher, An Investigation of Occupants' Energy Perceptions in Energy Efficient Retrofitted Residential Buildings: A Review Paper. IOP Conference Series: Earth and Environmental Science, IOP Publishing, 2022.
[45] A. Asikainen, et al., Reducing burden of disease from residential indoor air exposures in Europe (HEALTHVENT project), Environ. Health 15 (1) (2016) 61–72.
[46] S. Chatterjee, D. Ürge-Vorsatz, Measuring the productivity impacts of energy-efficiency: The case of high-efficiency buildings, J. Clean. Prod. 318 (2021) 128535.
[47] S. Breukers, L. van Summeren, R. Mourik, Project BoB (Bewoners ontmoeten Bouwers) Eerst proces, dan prestatie, in Uitgebreide Samenvatting, *('first the Process, Then Performance*') (2014). Study for Platform 31.
[48] Dijkstra, A. and J. Brouwer, *Bewonerscommunicatie bij duurzame woningverbetering*. Praktisch handboek voorprojectleiders en hun medespelers. 2010: Æneas, Boxtel.
[49] S.U. Boess, Design Contributions to Building Technology: Goals, Interfaces and Responsiveness, Cambridge University Press, 2019.
[50] G. Trotta, Factors affecting energy-saving behaviours and energy efficiency investments in British households, Energy Policy 114 (2018) 529–539.
[51] G.P. Latham, E.A. Locke, Self-regulation through goal setting, Organ. Behav. Hum. Decis. Process. 50 (2) (1991) 212–247.
[52] T. Croon, et al., Beyond Headcount Statistics: Exploring the Utility of Energy Poverty Gap Indices in Policy Design. 177 (2023) 113579.
[53] S. Alavirad, et al., Future-Proof Energy-Retrofit Strategy for an Existing Dutch Neighbourhood. 260 (2022) 111914.
[54] R. Escandón, et al., Evaluating the Environmental Adaptability of a Nearly Zero Energy Retrofitting Strategy Designed for Dutch Housing Stock to a Mediterranean Climate. 169 (2018) 366–378.