# Monetary and Non-Monetary Values of Energy Efficient Attributes in Residential Property: Do They Match?

**Abstract.** After the adoption of the National Climate Agreement by the Dutch House of Representatives, the use of renewable sources and energy efficient attributes in housing to create a climate neutral society by 2050 became one of the important long-term policy goals. The effect of energy efficiency in housing has been studied in the past, but the current body of literature lacks further insights into the comparison between the monetary and non-monetary effects of energy efficiency on the residential market. Such insights help to verify whether energy efficient attributes induce both a premium on the property price, caused by the willingness to pay, and increased residential satisfaction, leading to sufficient willingness to pay. This study compares and elaborates on how the monetary value of property and the non-monetary residential satisfaction of residents are affected as a result of energy efficient attributes in housing by performing hedonic pricing modelling and ordered logistic regressions using WoON 2018 data. The dataset includes information on Dutch demographics, household characteristics, property characteristics, and neighbourhood characteristics. The results show that the energy efficient attributes associated with property values have limited correspondence to the attributes which positively impact residential satisfaction. This finding suggests that the willingness to pay generated by residential satisfaction does only seem to induce a limited ability to charge premiums for the relevant energy efficient attributes. The limited correspondence observed in the analysis may be the result of factors like brown discounts, low capitalisation rates and financial incentives. This study adds to the existing body of literature by providing a comparison of both types of valuation and a better understanding of the underlying assumption of willingness to pay for energy efficient attributes in housing.

**Keywords.** Energy efficiency, property prices, residential satisfaction.

Danique van Beelen - S2950790

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# 1 Introduction

In 2019, the Dutch House of Representatives presented the National Climate Agreement as a path towards reaching the goals set out by the Paris Climate Agreement. Buildings are the source of approximately 40 percent of the total energy consumption and 36 percent of $CO_2$ emissions in the EU (European Commission, 2018), which makes it an important focus area of the National Climate Agreement for the goal to reduce greenhouse gas emissions. The Netherlands aims for a climate neutral society by 2050, where energy is generated by renewable sources (Rijksoverheid, n.d.b; EZK, 2019). To reach this goal, the Dutch government subsidises the (re)development of energy efficient properties and invests in education about energy efficiency to stimulate the use of sustainable energy sources such as heat pumps and solar panels (Rijksoverheid, n.d.b). Knowledge of the effects of energy efficiency on the residential market is important for understanding the rationale behind property transactions and to stimulate behavioural change (Ramos et al., 2015). Individuals who seek housing are increasingly looking for properties which are labelled as energy efficient. Around 90 percent of the potential buyers consider a high green label as an advantage or necessity (BPD, 2019). In recent years, there have been attempts to estimate the effects of green labels on property prices and residential satisfaction which could explain the trend observed by BPD (2019). Brounen & Kok (2011) found evidence for the positive impact of green labels on property prices in the Netherlands. They argue that properties which are classified as energy efficient induce property price premiums. But there are heterogenous views on the size of the premium induced by energy labels (see Olaussen et al., 2017; Murphy, 2014). On the contrary, Aydin et al. (2020) argued that the price premium is caused by the underlying attributes rather than the energy label itself. Furthermore, energy efficient attributes in residential properties may be part of an aspired lifestyle (Tan, 2014b). Several studies suggested that such lifestyle aspirations may increase residential satisfaction, which may lead to a higher willingness to pay (Tan, 2014a; Johnson, 2014). Residential satisfaction with energy efficiency may, in turn, increase the intention to repurchase another energy efficient property and increase the willingness to pay for such properties (Liu et al., 2019a; Mesthrige Jayantha & Sze Man, 2013). Yet, empirical evidence on the effects of the underlying energy efficient attributes on property prices and residential satisfaction remains relatively scarce.

While existing studies have established empirical evidence on the effects of green labels and energy efficiency on the residential property market, the current body of literature lacks emphasis on its effects on residential satisfaction and further insights into the comparison between the monetary and non-monetary effects of energy efficient on the residential market. The effect of energy efficiency on the residential market can be expressed in social and economic terms. To be able to charge a premium on property prices for energy efficient features, there must be an incentive or willingness to pay. Earlier research by Liu et al. (2019b) showed that merely a financial incentive is not sufficient to motivate individuals to pay additional premiums for energy efficient features in housing. To increase the willingness to pay a premium for such attributes, occupants should experience sufficient residential satisfaction. More work is needed to verify whether energy efficient attributes induce both a premium on the property price, caused by the willingness to pay, and increased residential satisfaction, leading to sufficient willingness to pay.

The present research aims to clarify *what the effect of energy efficient attributes is on the Dutch residential market in terms of the monetary and non-monetary valuation and how these valuations compare*. The analysis on the monetary valuation focuses the contribution of energy efficient attributes to property values by performing a hedonic pricing model. The non-monetary valuation was studied by performing an ordered logistic regression to understand the relationship between energy efficient attributes and residential satisfaction. Additional attention is paid to differentials based on the type of property and the type of tenure. To study the effects of energy efficient attributes on property value and residential satisfaction, information on individual, household, property, and locational characteristics from the WoON 2018 dataset was used. The results show that the energy efficient attributes associated with property values have limited correspondence to the attributes which positively impact residential satisfaction. This finding suggests that the willingness to pay generated by residential satisfaction does only seem to induce a limited ability to charge premiums for the relevant energy efficient attributes. The limited correspondence observed in the analysis may have been the result of factors like brown discounts, low capitalisation rates and financial incentives. This study adds to the existing body of literature by providing a comparison of both types of valuation and a better understanding of the underlying assumption of willingness to pay for energy efficient attributes in housing.

The remainder of this study is structured as follows. Chapter 2 reflects on the context of energy efficiency in the Dutch residential market. Chapter 3 presents a literature review, the conceptual model and the hypotheses. Chapter 4 discusses the methods and data which are used for the proposed study. In chapter 5 the results are presented, which is followed by the discussion and conclusion in chapter 6.

# 2 Context: Energy efficiency in the Dutch residential market

## 2.1 Energy labels and underlying energy efficient attributes

After the introduction of the EU Energy Performance of Building Directive (EPBD) in 2002, the Netherlands introduced mandatory energy labels as Energy Performance Certificates (EPC) for selling or renting a property from 2009 onwards (Van Hal et al., 2012). Since the introduction of EPC, the content and components of the energy labels have constantly changed to account for changing EU norms and new techniques. From January 1, 2022, onwards, the EPC is determined by the NTA 8800 method (RVO, n.d.). The current energy labels categorise the energy efficiency of houses into a classification ranging from A++++ (very energy efficient) to G (very inefficient), where comparable properties are used as the reference frame. Energy labels consist of six domains, which help to classify properties.

*Isolation* describes the extent to which a property is isolated and the quality of the isolation. *Installations* describes the type and quality of installations to heat the property and the water, to ventilate and to cool the house. *Natural gas* describes if the property still uses natural gas as a source of heating and what the potential is to transform the property to natural gas free. *Heating requirements during the winter* describes how much energy is needed to heat the property in the winter. *Indoor temperatures during the summer* describes the risk of high indoor temperatures during the summer. *Renewable energy* describes the ability of the property to generate renewable energy by sources such as solar panels (Milieu Centraal, n.d.). The publishing of energy labels generates transparency, awareness, and easily accessible information regarding energy efficiency on the residential market (Milieu Centraal, n.d.)

Figure 1 illustrates the number of registration of energy labels (x 1,000) for the Dutch housing stock during the period 2010-2019. The number of registrations increased over a decade and especially the share of energy efficient labels (A and B) increased since 2015. Although energy labels were already a mandatory part of the sale or rent of property since 2009, the presence of the label was not enforced or checked for. In 2015, new legislation caused enforcement for the presence of energy labels and created legal basis for fines if the seller could not deliver the energy label (CLO, 2016). This new legislation also introduced provisional energy labels assigned based on building type and building year. The definitive energy label has to be applied for at the moment a property is sold (Stangenberg et al., 2020). The overall increase of energy label registrations since 2015 was mainly caused by the simplification and reduction in costs of the registration process (CLO, 2020). The share of energy inefficient labels (E, F and G) decreased from 23 percent in 2010 to 16 percent in 2019, creating a more energy efficient housing stock.

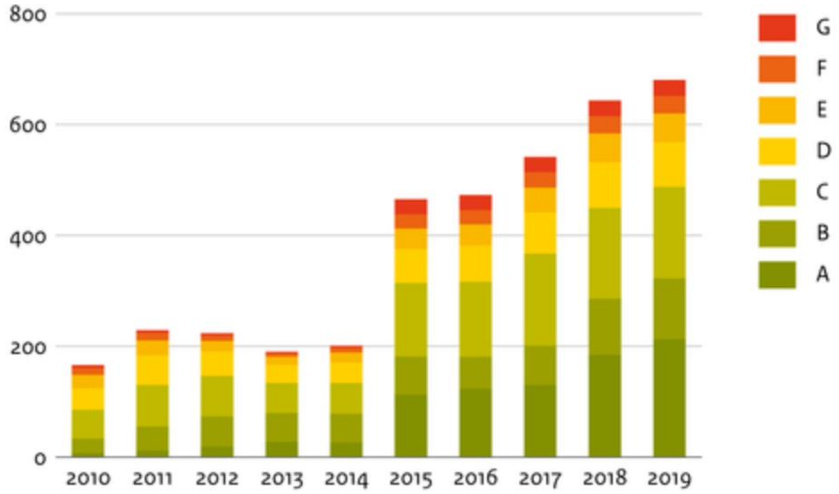


**Figure 1**. Energy labels of properties 2010-2019, number of properties x1,000 (CLO, 2020).

### 2.2 Financial incentives and policies to stimulate energy efficiency

The lack of financial resources oftentimes creates a barrier to energy efficient investments (Ebrahimigharehbaghi et al., 2019). To stimulate the implementation of energy efficient attributes on the residential market, the Dutch government has installed several financial incentives through policy. The main elements are the Homeowners Energy Saving Subsidy (SEEH), the National Energy Savings Fund to receive a loan of maximum €25,000, and the Sustainable Energy Investment Subsidy (ISDE) (BZK, n.d.). Yet, the application processes for the subsidies and loans are perceived as complex and a significant share of the population is not aware of the existence of these financial incentives. By implementing policy on increasing awareness and the spread of information, the use of financial incentives can be increased by removing the perceived obstacles (Ebrahimigharehbaghi et al., 2019). However, factors like financial return and the payback time remain important for both homeowners and tenants when considering investing in energy efficiency. Investments mostly take place on a relatively low pace, taking only small steps at the time (Vringer et al., 2016). Vringer et al. (2016) observed that financial incentives are often too weak to support larger investments and considerable progress on the Dutch residential market. Residents in areas with high socioeconomic status and a positive development of property prices are more often found to invest in energy efficiency using private financial resources (Vimpari, 2021). However, Lihtmaa et al. (2018) found that residents in areas with high socioeconomic status are also better able to be granted the subsidies. Meanwhile, energy efficiency and the lower consumption of energy are capitalised into higher transaction prices (Aydin et al., 2020). The allocation of subsidies into areas with low socioeconomic status is, thus, important to evenly distribute energy efficiency and to increase demand for these properties (Vimpari, 2021).

# 3 Literature review

### 3.1 Property prices and energy efficiency

Since the prevalence of energy efficiency and energy labels in the Netherlands increased since the 2010s, an increasing number of studies focused on the price premiums induced by energy efficiency (Stangenberg et al., 2020; Chegut et al., 2016). Yet, empirical findings on the effect of a property price premium induced by energy labels are heterogeneous. Brounen & Kok (2011) observed a property price premium associated with energy labels in the Netherlands, whereas Murphy (2014) found that only a small share of property values in the Netherlands is affected by energy labels during the transaction process. Olaussen et al. (2017) argue that energy labels only have a minor influence on Norwegian residential market values after controlling for fixed effects in the model. Stangenberg et al. (2020) analysed the price changes of properties before and after the introduction of energy labels on the Dutch residential market. Although they found that properties with relatively high energy labels were sold at a premium, many of these properties already were sold at significantly higher prices before the introduction of energy labels. Furthermore, Student et al. (2017) studied the willingness to pay for energy labels on the Dutch residential market. Interestingly, Student et al. (2017) observed that over a quarter of the potential homebuyers are not willing to pay any premium for the presence of an energy label, whereas Brounen & Kok (2011) observed willingness to pay a premium for a label indicating energy efficiency.

Aydin et al. (2020) found that it is not the energy label that increases the transaction price of houses, but the presence of the underlying energy efficient attributes that reflects the price premium. This is argued to be the result of the capitalisation of reduced energy consumption in the value of a property. Individuals may also aspire an eco-friendly and green lifestyle, which increases the demand for energy efficient housing. Following the theory of an efficient market, the increased demand can lead to increased property prices *ceteris paribus* (Tan, 2014b). There have been attempts to estimate the effect of individual energy efficient attributes on the value of property, which underly the energy labels of properties. Hurst & Halvitigala (2020) studied the effect of solar technology on transaction prices in the Australian housing market. They observed inconclusive findings for the willingness to pay a premium for solar energy efficient attributes, where the income levels of households had a strong impact. Sayce & Wilkinson (2019) argue that energy efficient attributes slowly start to affect the value of properties within the EU. They observed that double glazing has the largest impact on property values in the EU. Furthermore, Vimpari (2021) argues that heat pumps are one of the most profitable energy efficient attributes as they reduce energy consumption and induce increased real estate premiums.

Although energy efficient attributes may induce property price premiums, they may also involve 'brown discounts', where properties which lack energy efficiency may be characterised by property values below the mean. In the case of brown discount, specific characteristics thus do no increase property values, which may distort findings on induced premiums. Furthermore, the Dutch property market reflects only small levels of capitalisation of energy efficient attributes compared to other EU countries; only 1 percent of the property price may be explained by energy efficient attributes, compared to a much larger share by property and locational characteristics (Sayce & Wilkinson, 2019).

## 3.2 Residential satisfaction and energy efficiency

### *3.2.1 Residential satisfaction theory*

The proposed framework of Liu et al. (2019b) attributes residential satisfaction as an important determinant for the willingness to pay for energy efficiency. Although residential satisfaction has been used in different types of theories and frames, the common use of residential satisfaction is to measure the difference between the current residential situation and the aspired residential situation. Based on the evaluation of the current and aspired residential situation, residents may or may not experience satisfaction with the current residential situation. In case an individual is not satisfied with the current residential situation, there exists an 'aspiration gap' (Tan, 2014b). By the introduction of *housing needs* *theory*, Rossi (1955) gave attention to the effects of the life cycle course on the housing needs. The course through an individual's life cycle cycles can cause changed aspirations and, thus, changed residential satisfaction. Although individuals are assumed to be rational beings and choose a desired living situation, the changing aspiration may lead to dissatisfaction with the living situation. Migration is often understood to be a response to such dissatisfaction or an aspiration gap (Tan, 2014b; Smrke et al., 2018; Galster & Hesser, 1981; Mohit et al., 2010; Coolen & Hoekstra, 2001).

The *theory of residential satisfaction* describes how compositional characteristics of individuals, households, the context of the property and the context of the neighbourhood help to shape residential satisfaction (Galster & Hesser, 1981). There are two approaches to studying residential satisfaction. First, it is possible to do a general measurement and analysis on residential satisfaction. Second, specific factors or attributes which are related to residential satisfaction can be studied (Smrke et al., 2018). By studying the contribution of specific factors or attributes to residential satisfaction, they transform from objective to subjective attributes. The objective characteristics of the residential environment form an individual's impressions, which affect the subjective characteristics of the residential environment. There is a normative evaluation of the attributes, which results in an individual level of residential satisfaction (Mohit et al., 2010). To control and account for the differences found between individuals and their experiences, individual, household, property and locational characteristics are used in empirical modelling (Adriaanse, 2007; Galster & Hesser, 1981).

### *3.2.2 Energy efficient attributes and residential satisfaction*

To create sufficient ground to influence residential satisfaction, the presence of energy efficient attributes in housing has to contribute to the reduction of the aspiration gap of occupants. The popularity of energy efficient attributes and sustainable techniques in housing has increased in recent decades. This is the result of lower expected energy consumption and increased returns. Depending on the desires of individuals to be sustainable, the implementation of energy efficient attributes can influence residential satisfaction. This phenomenon occurs in two different ways: saving money due to energy efficiency and achieving the goal to be sustainable (Fornara et al., 2007). Owning an energy efficient property may satisfy the desire to have an eco-friendly lifestyle and the housing expenses may decrease due to the cost savings induced by energy efficiency (Tan, 2014b; Fornara et al., 2007). Tan (2014b) observed that attributes which lead to energy efficiency, water efficiency, and improved indoor air quality have a positive effect on residential satisfaction. Some of the most valued energy efficient attributes were found to be solar panels, double glazing, LED lighting, cross ventilation and heat insulation (Tan, 2014b). Although many attributes provide direct effects, there may also be indirect effects involved. For example, better indoor air quality leads to increased productivity and physical performance, which can result in higher residential satisfaction (Fisk, 2000). However, the implementation of such attributes needs to come with shifts in attitudes towards sustainability (Tan, 2014b), while the financial support system of Dutch policy does not suffice to generate considerable investments and progress on the Dutch residential market (Vringer et al., 2016).

### 3.3 Motivations and consumer behaviour underlying energy efficiency

Given the investment needed to reach or enhance energy efficiency in residential property, there must be a form of motivation for the household or homeowner to act upon. Rather than consideration, households and homeowners need to experience sufficient levels of motivation to act upon and invest (Liu et al., 2019b; Murphy, 2014). There are three main types of motivations for individuals to implement energy efficient attributes: (1) *economic*, (2) *social*, and (3) *environmental*. The economic motivation is driven by a (potential) decrease in energy consumption, the availability of economic resources to invest, the household income and the increased value of property. The social motivation includes increased comfort, social norms, responsible behaviour and social expectations. The environmental motivation involves improved carbon footprint and a decreased environmental impact (Organ et al., 2013). Sufficient levels of economic, social and environmental incentive to implement energy efficiency can lead to the willingness to pay for such attributes (Liu et al., 2019b). But there remains a gap between the potential for energy efficiency and the realisation of energy efficiency in housing. Abrardi (2019) argues that there are two main reasons for this observation. First, there is underinvestment and, second, efficiency can lead to behaviours of overconsumption. This implies that consumer irrationality can lead to energy inefficiency (Abrardi, 2019). Noonan et al. (2015) argue that homeowners "systematically undervalue energy efficiency upgrades because energy consumption includes unpriced negative externalities" (p. 111), such as renovations and changes in behaviour to achieve benefits from the energy efficient attributes. But also the investment needed from homeowners play an important role. Homeowners have to finance the implementation of energy efficient attributes themselves or by using subsidies to (partially) cover the costs. The *double-entry mental accounting theory* can explain consumer behaviour towards the implementation of energy efficient attributes. The investment in energy efficient attributes involves the direct *pain of paying*. Depending on the chosen attributes, the homeowner will experience the *pleasure of consumption* within weeks or months because they save energy, which is also called the 'rebound effect' (Li et al., 2019; Noonan et al., 2015). The foresight that the market value of their property increases, stimulates a share of the households to invest in energy efficient attributes (Murphy, 2014). Also the belief that energy savings will lead to cheaper a living situation in the long run is a driving force (Tan, 2014b). There are, thus, a number of incentives and motivations, although consumer irrationality may disturb individuals to act upon them.

### 3.4 Differentials between rental and owner-occupied properties

The residential property market shows clear differentials between rental and owner-occupied properties; in terms of property prices and energy efficiency. Rental properties continue to be sold for lower prices than owner-occupied properties as a result of poor maintenance and inappropriate use by tenants (Turnbull & Van der Vlist, 2022). Next to the lower transaction price of rental property, private rental properties continue to perform the worst in terms of energy efficiency. One of the main reasons for this phenomenon is that a large share of landlords does not gain any direct benefit from the investment as the tenants oftentimes pay for the energy and gas consumption. There remains a lack of legal obligations for landlords to invest in energy efficient attributes (Hope & Booth, 2014). Furthermore, tenants may not enjoy the similar long-term benefits from energy efficiency as homeowners do. While homeowners are the direct beneficiaries of energy efficient investments, this is not always the case for tenants. There may be a "split incentives problem", where landlords are less interested in investing in energy efficiency than tenants when the landlord does not pay for the energy costs (Krishnamurthy & Kriström, 2013; Davis, 2011). If energy efficiency is aspired, landlords may earn back on their investments by raising the rents in the case they are allowed to do so. The increased rental costs for tenants may result in residential dissatisfaction (Lu, 1999). Carroll et al. (2016) argue that there is "a clear owner-renter energy efficiency divide" (p.617). When considering permanent investments, such as the insulation of walls and roofs, the irreversible and non-mobile nature of such investments makes it only feasible to the landlord (Carroll et al., 2016). However, the landlord may experience constraints to invest due to limited financial resources, a lack of knowledge of energy efficiency, or maximised investment where the discounted marginal return of the rent income is equal to the cost of capital (Hope & Booth, 2014; Carroll et al., 2016). Based on a discrete choice model experiment including tenants, Caroll et al. (2016) found that tenants appreciate the presence of energy efficient attributes, but the willingness to pay for such attributes is mainly limited to improvements in energy inefficiency. Gabe & Rehm (2014) found no significant differences in rental costs when comparing rental properties with different levels of energy efficiency. They concluded that tenants are not willing to pay a premium for energy efficiency. The type of tenure can thus be a problematic factor for residents in reaching their energy efficiency related aspirations.

### 3.5 Conceptual model and hypotheses

Based the current body of literature on energy efficiency, property values and the residential satisfaction theory, the conceptual model for this study is presented in figure 2. The social and economic effects of energy efficiency on the residential property market are linked through willingness to pay as discussed earlier in the framework of Liu et al. (2019b). Residential satisfaction with energy efficient attributes or the aspirations to implement such attributes leads to motivation and incentives to act upon, which induces a willingness to pay. Motivation to invest can be induced by factors like aspired eco-friendly lifestyles or the prospective energy consumption savings (Tan, 2014b; Fornara et al., 2007; Liu et al., 2019b; Murphy, 2014). The willingness to pay for energy efficient attributes provides the opportunity to be able to charge premiums on property prices for the presence of attributes (Liu et al., 2019b). To verify whether energy efficient attributes induce both monetary and non-monetary effects, this study compares property prices and residential satisfaction as illustrated by the dotted line in figure 2. The conceptual model provides an overview of the comparison between property prices and residential satisfaction, and the underlying determinants identified in previous studies. The determinants for property values can be grouped into energy efficient attributes and property and locational characteristics (Sayce & Wilkinson, 2019). Residential satisfaction determinants can be grouped into energy efficient attributes, property and locational characteristics, and individual and household characteristics (Adriaanse, 2007; Galster & Hesser, 1981). Figure 2 shows the grouped determinants and the paths via which they may affect property values and residential satisfaction.

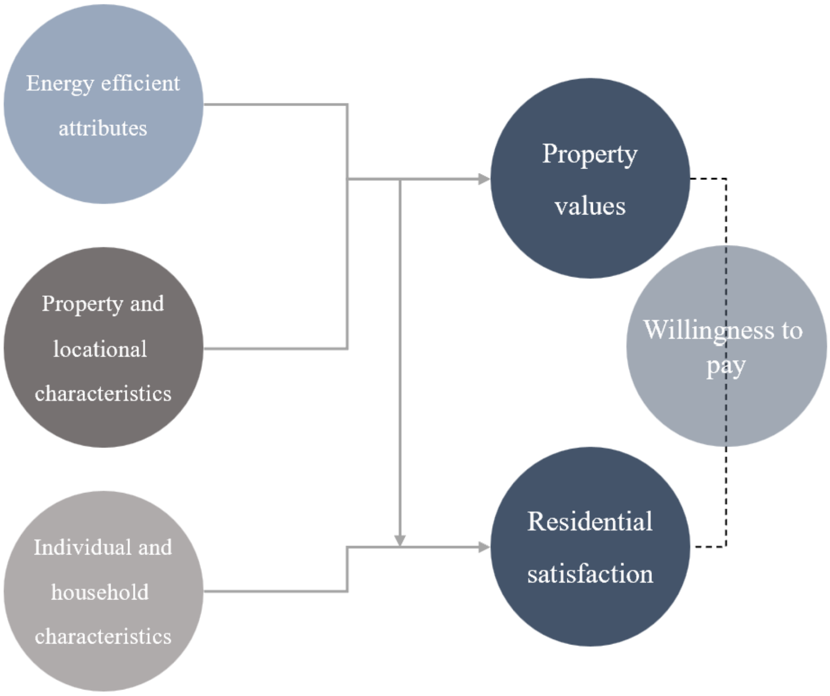


**Figure 2.** Conceptual model.

To test the above outlined framework, it is hypothesised that *the monetary valuation of energy efficient attributes in terms of the property value premium corresponds with the non-monetary valuation in terms of residential satisfaction*. In other words, the energy efficient attributes which positively affect residential satisfaction are expected to be positively associated with an increase in property value, and vice versa. To understand the monetary valuation of energy efficient attributes, this study elaborates on *to what extent energy efficient attributes in the residential market affect property values in the Netherlands.* The non-monetary valuation of energy efficient attributes is studied by addressing *to what extent energy efficient attributes influence the residential satisfaction of residents in the Netherlands.* Given the clear differences between rental and owner-occupied properties in the market and differences in the behaviour of homeowners and tenants as outlined in the literature, additional attention is paid to possible differentials between those groups. The results on the monetary and non-monetary valuations are used to provide a comparative view between the social and economic effect of energy efficiency.

# 4 Methods

## 4.1 Data and study area

This study makes use of the WoON dataset[1], which comprises information on the housing situation and needs of Dutch households. The WoON dataset is a survey which includes approximately 63,000 households and which is distributed every three years. The data holds information on Dutch demographics, household characteristics, property characteristics, and neighbourhood characteristics. The data sampling is done based on random sampling, which makes the dataset representative for the residential market of the Netherlands. The study is limited to the cross-sectional use of WoON 2018 due to missing data on energy efficient attributes in earlier editions. The data from WoON 2018 is cleaned by removing outliers or missing values and recoding several variables for intuitive understanding and interpretation.

## 4.2 Hedonic pricing model

### *4.2.1 Property price composition*

The unique bundle of characteristics for each property makes it a heterogeneous good. Because of the large degree of heterogeneity, defining the monetary value of the separate characteristics can be complex. An often used technique to understand the value of house characteristics is *hedonic pricing modelling*, which helps to determine the added value of individual characteristics (Sirmans et al., 2005; Francke & Van de Minne, 2021). It is important to critically review the included characteristics in the hedonic price model to prevent misspecification or unobserved heterogeneity, which causes complexity for the modelling of property prices. Some of the most occurring characteristic categories in the modelling of property prices are the building structure, internal features, external amenities, and the environment (Sirmans et al., 2005; Francke & Van de Minne, 2021).

A large variety of variables has been used in previous studies to better understand how property prices are composed. Evidence from previous studies shows that the most important and most often used property characteristics in price modelling are the number of rooms, floor area, type of property, age, outside areas, structural features and the quality of the property or used materials (Malpezzi, 2003;

[1] Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (BZK) & Centraal Bureau voor de Statistiek (CBS) (2019). *WoON2018: release 1.0 - Woononderzoek Nederland 2018.* DANS.

Sirmans et al., 2005; Herath & Gunther, 2010). These characteristics generally all are associated with positive signs, or price premiums, except for age (Sirmans et al., 2005). Furthermore, there exist large price differences across and between geographical regions. Due to the capitalisation of environmental and locational characteristics, property prices can differ across space (Gong, 2017). Studies performed by Visser et al. (2008) and Van Duijn et al. (2015) included variables on neighbourhood or locational characteristics, such as the presence of parks and woods, the distance to amenities, population density and population composition. But the property markets on regional geographical level may also experience different trends, which may cause larger price changes or different types of dynamics for one market than another (Gelfand et al., 2004; Gong, 2017). Given that property prices partially reflect the valuation of the environment of a property by individuals, it is relevant to include variables to account for spatial variation (Visser et al., 2008).

*4.2.2 Operationalisation of variables*

The WOZ value of property is used to estimate the hedonic pricing model. The WOZ value is the value of an individual's property as determined by the municipality and is used for tax purposes. This value can change every year and can differ from the price which was paid for the property at the moment of purchase (Mohit et al., 2010; Lu, 1999). The WoON dataset holds the WOZ value with 2016 as the reference year. Further analysis employs transaction price, which is only available for owner-occupied properties and thus leads to a smaller number of observations. The distributions of WOZ value and transaction price skewed, as a result of which the natural logarithms were used as dependent variable.

The main independent variables in the hedonic pricing model are the different energy efficient attributes. The energy efficient attributes in the WoON data are the following variables: double glazing, solar panels, isolation of the roof, walls, floors and ceilings, heat pumps, city or district heating, and renewed or new central heating installation. To control for heterogeneity between properties, a set of characteristics is included in the model. The property characteristics includes the number of rooms, surface area, type of property, building year, outside areas, and type of parking (Herath & Maier, 2010; Tajani et al., 2020). Although the variable holding information on property types includes a range of options, a number of types of properties have only a very limited number of observations. To prevent unwanted noise or disturbances in the analysis, the property types included in the analysis are limited to apartments and terraced properties. Locational characteristics of the environment surrounding a specific property may also affect the value of the property. The analysis includes distance to the supermarket, distance to the highway and the level of urbanity (Visser et al., 2008; Van Duijn et al., 2014). Last, the 40 COROP regions in the Netherlands are used to control for location fixed effects which may cause price differences between properties in different regions. Table 1 provides the summary statistics of the variables used in the analysis. Binary variables are represented by a 0/1 option, where 0 indicates "No" and 1 indicates "Yes".

**Table 1.** Summary statistics of the sample for the hedonic pricing model.

| Variables | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| **Ln WOZ value** | 16,168 | 11.88 | 0.349 | 10.60 | 13.29 |
| **Ln Transaction price** | 3,377 | 12.07 | 0.446 | 10.21 | 13.24 |
| **Energy efficient attributes** | | | | | |
| Heating pump | 16,168 | 0.0106 | 0.102 | 0 | 1 |
| City/district heating | 16,168 | 0.0589 | 0.235 | 0 | 1 |
| Double glazing | 16,168 | 0.243 | 0.429 | 0 | 1 |
| Isolation | 16,168 | 0.149 | 0.357 | 0 | 1 |
| Solar panel | 16,168 | 0.0520 | 0.222 | 0 | 1 |
| New central heating | 16,168 | 0.300 | 0.458 | 0 | 1 |
| **Property characteristics** | | | | | |
| Number of rooms | 16,168 | 3.640 | 1.066 | 1 | 7 |
| Surface area property | 16,168 | 88.75 | 24.90 | 30 | 202 |
| Surface area living room | 16,168 | 33.20 | 16.41 | 12 | 103 |
| **Property type** | | | | | |
| Apartment | 16,168 | 0.514 | 0.500 | 0 | 1 |
| Terraced | 16,168 | 0.486 | 0.500 | 0 | 1 |
| **Type of tenure** | | | | | |
| Homeowner | 16,168 | 0.210 | 0.407 | 0 | 1 |
| Tenant | 16,168 | 0.790 | 0.407 | 0 | 1 |
| **Building year** | | | | | |
| Before 1945 | 16,168 | 0.0927 | 0.290 | 0 | 1 |
| 1945-1959 | 16,168 | 0.111 | 0.314 | 0 | 1 |
| 1959-1969 | 16,168 | 0.176 | 0.381 | 0 | 1 |
| 1969-1979 | 16,168 | 0.195 | 0.396 | 0 | 1 |
| 1979-1989 | 16,168 | 0.190 | 0.392 | 0 | 1 |
| 1989-1999 | 16,168 | 0.104 | 0.305 | 0 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| 1999-2009 | 16,168 | 0.0768 | 0.266 | 0 | 1 |
| After 2009 | 16,168 | 0.0555 | 0.229 | 0 | 1 |
| | | | | | |
| **Outside area** | | | | | |
| Balcony | 16,168 | 0.433 | 0.496 | 0 | 1 |
| Garden | 16,168 | 0.553 | 0.497 | 0 | 1 |
| Patio | 16,168 | 0.0126 | 0.112 | 0 | 1 |
| Courtyard | 16,168 | 0.0264 | 0.160 | 0 | 1 |
| Surrounding parcel | 16,168 | 0.0115 | 0.107 | 0 | 1 |
| | | | | | |
| **Type of parking** | | | | | |
| Private parking | 16,168 | 0.0907 | 0.287 | 0 | 1 |
| Shared parking | 16,168 | 0.444 | 0.497 | 0 | 1 |
| No parking | 16,168 | 0.465 | 0.499 | 0 | 1 |
| | | | | | |
| **Distances to amenities** | | | | | |
| Distance to supermarket m. | 16,168 | 634.9 | 420.9 | 0 | 3,233 |
| Distance to highway m. | 16,168 | 1,695 | 889.9 | 23 | 4,635 |
| | | | | | |
| **Level of urbanity** | | | | | |
| Low | 16,168 | 0.220 | 0.414 | 0 | 1 |
| Middle | 16,168 | 0.161 | 0.368 | 0 | 1 |
| High | 16,168 | 0.619 | 0.486 | 0 | 1 |

*4.2.3 Empirical model*

To estimate the effect of energy efficient attributes on the property value, a hedonic price model was estimated using the following specification:

$$Ln\,WOZ\,value_{i,k} = \alpha + \beta_1 * Energy\,efficient\,attribute_1 + \cdots + \beta_X * Energy\,efficient\,attribute_X + \sum_{k=1}^{K} X_{i,k} + \theta_k + \varepsilon_{i,k} \quad (1)$$

where Ln WOZ value$_{i,k}$ represents the natural logarithm of the WOZ value of a house *i* in location *k*. $\alpha$ represents the constant and $\beta_X$ represents the estimated coefficient for the relevant independent variable, which is based on the set of energy efficient attributes. $X_{i,k}$ represents the set of property and locational characteristics and $\theta_k$ represents the locational fixed effects. $\varepsilon_{i,k}$ represents the error term. The coefficients which are estimated by the model are, thus, $\alpha$, $\beta_X$, $X_{i,k}$ and $\theta_k$.

## 4.3 Ordered logistic regression model

The dependent variable *residential satisfaction* is used to estimate the effect of energy efficient attributes on an individual's residential satisfaction. Due to the ordinal nature of this variable, the analysis is executed based on an ordered logistic regression model. This type of logistic regression assumes that the dependent variable consists of three or more categories and has ordering between the categories (Mehmetoglu & Jakobsen, 2017). The use of an ordered logistic regression model prevented the loss of information on the ordering of residential satisfaction.

### *4.3.1 Operationalisation of variables*

Residential satisfaction is an ordinal variable measured by the WoON survey by the question "*How satisfied are you with your current home?*", where respondents answer the question on a five-point Likert scale from 1 'very dissatisfied' to 5 'very satisfied'.

To measure the effect of energy efficiency on an individual's residential satisfaction, the energy efficient attributes (see section 4.2.2) are included as main independent variables. Other categories of variables which are controlled for are individual characteristics, household characteristics, property characteristics, and locational characteristics. The current life cycle status of individuals and households is an important determinant of residential satisfaction. On the individual level, the life cycle status can be represented by the age of the respondent (Galster & Hesser, 1981). Other individual determinants are the ethnicity (Quang Tran & Van Vu, 2017; Lu, 1999), the level of education (Quang Tran & Van Vu, 2017; Lu, 1999), and self-reported health (Ren et al., 2018). The life cycle status is also connected to the household characteristics which influence residential satisfaction, represented by the household composition and the possible presence of children within the household (Galster & Hesser, 1981). Tenure status is another important determinant for the residential satisfaction of households. Many studies observed significantly higher residential satisfaction statuses for homeowners than for tenants (Mohit et al., 2010). This is the result of a "sense of self-gratification" (Mohit et al., 2010, p.20) causes a more psychologically satisfied feeling among homeowners. Last, the financial basis of a household is an important determinant of residential satisfaction. High socioeconomic status and high household incomes are correlated with relatively higher residential satisfaction (Lu, 1999; Galster & Hesser, 1981). Empirical studies on the costs of housing and housing expenses showed that decreased costs and expenses lead to increased residential satisfaction (Lu, 1999).

The second set of compositional characteristics influencing residential satisfaction includes the property and locational features. Previous studies have included a variety of property characteristics to study residential satisfaction. These characteristics included the number of rooms (Elsinga & Hoekstra, 2005), type of property (Mohit et al., 2010; Elsinga & Hoekstra, 2005; Quang Tran & Van Vu, 2007), surface area of property and living room (Boumeester, 2011; Mohit et al., 2010), the ratio rooms – people (Lu, 1999; Elsinga & Hoekstra, 2005), building year (Mohit et al., 2010), type of parking (Boumeester, 2011), and architecture (Boumeester, 2011). The direct environment surrounding a property may also affect an individual's residential satisfaction (Galster & Hesser, 1981). Social locational characteristics like cohesion in the neighbourhood positively affect residential satisfaction as there will exist a sense of involvement and participation (Aulia & Ismail, 2013; Mohit et al., 2010; Amérigo & Aragonés, 1990). More structural locational characteristics which influence residential satisfaction are the level of urbanity (Galster & Hesser, 1981) and the presence of facilities and amenities (Amérigo & Aragonés, 1990; Mohit et al., 2010). Table 2 provides the summary statistics of the variables used in the analysis. Binary variables are represented by a 0/1 option, where 0 indicates "No" and 1 indicates "Yes".

When comparing the summary statistics of the hedonic pricing model sample in table 1 and the ordered logistic regression sample in table 2, some noticeable similarities and differences can be observed. The presence of energy efficient attributes seems to be similar between the two samples, where only slight differences in the mean are observed. The surface area of properties in the ordered logistic regression sample in table 2 is considerably higher with 8 square metres. Although both samples consist of relatively equal shares of apartments and terraced properties, the hedonic pricing sample in table 1 is slightly dominated by apartments and the ordered logistic regression sample in table 2 is slightly dominated by terraced properties. A key difference between the samples is observed for the type of tenure. The ordered logistic regression sample in table 2 shows a relatively equal share of homeowners and tenants, while the sample of the hedonic pricing model has a considerably larger share of rental properties than owner-occupied properties. Although the hedonic pricing model will not be heavily affected because it objectively estimates property values, this observation should be taken into account.

**Table 2.** Summary statistics of the sample for the ordered logistic regression model.

| Variables | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| **Residential satisfaction** | | | | | |
| Very dissatisfied | 29,062 | 0.0138 | 0.117 | 0 | 1 |
| Dissatisfied | 29,062 | 0.0379 | 0.191 | 0 | 1 |
| Neutral | 29,062 | 0.132 | 0.338 | 0 | 1 |
| Satisfied | 29,062 | 0.502 | 0.500 | 0 | 1 |
| Very satisfied | 29,062 | 0.315 | 0.465 | 0 | 1 |
| **Energy efficient attributes** | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Heating pump | 29,062 | 0.0106 | 0.102 | 0 | 1 |
| City/district heating | 29,062 | 0.0558 | 0.230 | 0 | 1 |
| Double glazing | 29,062 | 0.249 | 0.432 | 0 | 1 |
| Isolation | 29,062 | 0.160 | 0.367 | 0 | 1 |
| Solar panel | 29,062 | 0.0556 | 0.229 | 0 | 1 |
| New central heating | 29,062 | 0.327 | 0.469 | 0 | 1 |
| | | | | | |
| **Age of respondent** | | | | | |
| 17-24 | 29,062 | 0.0228 | 0.149 | 0 | 1 |
| 25-34 | 29,062 | 0.175 | 0.380 | 0 | 1 |
| 35-44 | 29,062 | 0.160 | 0.366 | 0 | 1 |
| 45-54 | 29,062 | 0.180 | 0.384 | 0 | 1 |
| 55-64 | 29,062 | 0.183 | 0.387 | 0 | 1 |
| 65-74 | 29,062 | 0.158 | 0.365 | 0 | 1 |
| 75 or older | 29,062 | 0.120 | 0.325 | 0 | 1 |
| | | | | | |
| **Education of respondent** | | | | | |
| Low | 29,062 | 0.360 | 0.480 | 0 | 1 |
| Middle | 29,062 | 0.326 | 0.469 | 0 | 1 |
| High | 29,062 | 0.314 | 0.464 | 0 | 1 |
| | | | | | |
| **Ethnicity of respondent** | | | | | |
| Autochthonous | 29,062 | 0.817 | 0.386 | 0 | 1 |
| Non-western | 29,062 | 0.0854 | 0.279 | 0 | 1 |
| Western | 29,062 | 0.0972 | 0.296 | 0 | 1 |
| | | | | | |
| **Health of respondent** | | | | | |
| Very bad | 29,062 | 0.0419 | 0.200 | 0 | 1 |
| Bad | 29,062 | 0.0837 | 0.277 | 0 | 1 |
| Neutral | 29,062 | 0.156 | 0.363 | 0 | 1 |
| Good | 29,062 | 0.528 | 0.499 | 0 | 1 |
| Very good | 29,062 | 0.190 | 0.393 | 0 | 1 |
| | | | | | |
| **Household composition** | | | | | |
| One person | 29,062 | 0.406 | 0.491 | 0 | 1 |
| Couple | 29,062 | 0.282 | 0.450 | 0 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| Couple with children | 29,062 | 0.230 | 0.421 | 0 | 1 |
| Single parent | 29,062 | 0.0830 | 0.276 | 0 | 1 |
| | | | | | |
| **Household income** | 29,062 | 50,382 | 35,946 | 0 | 1.250e+06 |
| | | | | | |
| **Household expenses** | 29,062 | 787.8 | 317.2 | 47.84 | 2,399 |
| | | | | | |
| **Type of tenure** | | | | | |
| Homeowner | 29,062 | 0.492 | 0.500 | 0 | 1 |
| Tenant | 29,062 | 0.508 | 0.500 | 0 | 1 |
| | | | | | |
| **Number of rooms** | 29,062 | 3.921 | 1.188 | 1 | 8 |
| | | | | | |
| **Surface area** | 29,062 | 96.75 | 29.69 | 30 | 259 |
| | | | | | |
| **Rooms-people ratio** | 29,062 | 2.399 | 0.533 | 1 | 3 |
| | | | | | |
| **Property type** | | | | | |
| Apartment | 29,062 | 0.410 | 0.492 | 0 | 1 |
| Terraced | 29,062 | 0.590 | 0.492 | 0 | 1 |
| | | | | | |
| **Building year** | | | | | |
| Before 1945 | 29,062 | 0.158 | 0.365 | 0 | 1 |
| 1945-1959 | 29,062 | 0.0942 | 0.292 | 0 | 1 |
| 1960-1969 | 29,062 | 0.149 | 0.356 | 0 | 1 |
| 1970-1979 | 29,062 | 0.176 | 0.380 | 0 | 1 |
| 1980-1989 | 29,062 | 0.179 | 0.384 | 0 | 1 |
| 1990-1999 | 29,062 | 0.106 | 0.308 | 0 | 1 |
| 2000-2009 | 29,062 | 0.0806 | 0.272 | 0 | 1 |
| After 2009 | 29,062 | 0.0574 | 0.233 | 0 | 1 |
| | | | | | |
| **Parking** | | | | | |
| Private parking | 29,062 | 0.110 | 0.313 | 0 | 1 |
| Shared parking | 29,062 | 0.394 | 0.489 | 0 | 1 |
| No parking | 29,062 | 0.496 | 0.500 | 0 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| **Neighbourhood satisfaction** | | | | | |
| Very dissatisfied | 29,062 | 0.0171 | 0.130 | 0 | 1 |
| Dissatisfied | 29,062 | 0.0491 | 0.216 | 0 | 1 |
| Neutral | 29,062 | 0.131 | 0.338 | 0 | 1 |
| Satisfied | 29,062 | 0.531 | 0.499 | 0 | 1 |
| Very satisfied | 29,062 | 0.272 | 0.445 | 0 | 1 |
| | | | | | |
| **Neighbourhood cohesion** | 29,062 | 6.359 | 1.720 | 0 | 10 |
| | | | | | |
| **Urbanity** | | | | | |
| Low | 29,062 | 0.200 | 0.400 | 0 | 1 |
| Middle | 29,062 | 0.172 | 0.377 | 0 | 1 |
| High | 29,062 | 0.628 | 0.483 | 0 | 1 |

*4.3.2 Empirical model*

The variable residential satisfaction is an ordinal variable of five categories, ranging from 'very dissatisfied' to 'very satisfied'. The categorisation of the variable creates four cut points in the classification model, which represent the divisions between the five categories of residential satisfaction. The cut points can be considered thresholds for the different categories. The model observes ordinal variable *y*, represented by residential satisfaction in the model. In the ordered logistic regression model an unmeasured latent variable $y*$ helps to determine the value of *y*. The value of *y*, represented by a specific category of residential satisfaction, depends on which threshold the value of $y*$ crosses. The cut points can be expressed as follows:

$$y_i = \begin{cases} Very\ dissatisfied \\ Dissatisfied \\ Neutral \\ Satisfied \\ Very\ satisfied \end{cases} = \begin{cases} 1 & \text{if } y^* \leq \theta_1 \\ 2 & \text{if } \theta_1 < y^* \leq \theta_2 \\ 3 & \text{if } \theta_2 < y^* \leq \theta_3 \\ 4 & \text{if } \theta_3 < y^* \leq \theta_4 \\ 5 & \text{if } {\theta_4}^* < y^* \end{cases} \quad (2)$$

where $y_i$ presents the value for residential satisfaction and $y*$ presents the unmeasured latent variable used to determine the value of $y_i$. $\theta_i$ denotes the thresholds which form a specific category of residential satisfaction.

The ordered logistic regression model is estimated using the following specification:

$$\ln\left(\frac{p}{1-p}\right) = \beta_1 * Energy\ efficient\ attribute_1 + \cdots + \beta_X * Energy\ efficient\ attribute_X + \sum_{k=1}^{K} \phi_k X_{i,k} \quad (3)$$

where $p$ represents the probability of an outcome within a specific category of the categorisation *residential satisfaction*. $\beta_X$ represents the estimated coefficient for the relevant independent variable, which is based on a set of energy efficient measures. $\phi_i$ represents a set of individual and household characteristics and $X_{i,k}$ a set of property and locational characteristics. The coefficients which are estimated by the model are, thus, $\beta_X$, $\phi_k$, and $X_{i,k}$ .

### 4.4 Diagnostic testing

The hedonic pricing model and the ordered logistic regression model are tested based on the relevant regression assumptions. The assumptions relevant for the hedonic pricing model are *a conditional mean of zero for the error term*, *homoscedasticity*, *normally distributed errors, collinearity*, and *linearity*. The diagnostic testing indicates problems regarding heterogeneity and the distribution of errors. The distribution of the errors showed a slight skew. The large number of observations in the data prevented problems in the output as result of the skewness (Mehmetoglu & Jakobsen, 2017). Due to the heterogeneity in the model, robust standard errors are used. The use of robust standard errors provides better standard errors and more accurate p-values (Mehmetoglu & Jakobsen, 2017).

The ordered logistic regression model was tested for the assumptions of *collinearity*, *homoscedasticity*, *normally distributed errors*, *influential cases*, and *the parallel regression assumption*. The parallel regression assumption showed some variables where non-proportionality was found to be the case. As a considerable share of the variables is found to not be problematic regarding this assumption, the model estimation does not suffer from issues due to the violation (Lu, 1999). Given that the variables are of importance for correct estimations, it is decided to include in the analysis.

## 5 Results

The analysis is subject to two key influencing aspects regarding property characteristics. First, a key distinction can be made between owner-occupied properties and rental properties. As discussed in the literature, property prices and energy efficiency may be dependent on the type of tenure (see section 3.4). To prevent bias in the results, the data and analysis are separated based on the type of tenure. Furthermore, the energy consumption of different property types, such as apartments, terraced properties, and detached properties, inherits substantial differences between the different types. As a result, the energy consumption patterns may unevenly be affected by investments in energy efficient attributes. This leads to specific property type investments to optimise energy savings (Uidhir et al., 2020). To prevent disturbance from differences in consumption patterns, the owner-occupied properties and rental properties are sub-divided based on property type.

### 5.1 The impact of energy efficient attributes on the value of property

To study the effect of energy efficient attributes on the value of residential property in the Netherlands, a hedonic pricing model is estimated. Table 3 presents the estimation results based on the natural logarithm WOZ value of property. The estimation results include four models based on the grouping of (1) the type of tenure and (2) the type of property as discussed above. The hedonic pricing model includes energy efficient attributes, property characteristics, locational characteristics and location fixed effects.

Column 1 in table 3 presents the findings for owner-occupied apartments. The findings suggest that new central heating installations are significantly associated with a decrease in WOZ value of 3.13 percent[2]. Furthermore, the findings suggest that there is no association between the WOZ value of owner-occupied apartments and the other included energy efficient attributes. The estimation results for owner-occupied terraced properties are reported in column 2, table 3. Interestingly, none of the energy efficient attributes in the model are found to be significantly associated with the WOZ value of these properties. The estimated coefficients for rental apartments are reported in column 3, table 3. The presence of isolation in rental properties is found to be significantly associated with an increase in WOZ value of 2.01 percent. Furthermore, heat pumps are found to be significantly associated with an increase in WOZ value of 5.88 percent. Column 4 in table 4 presents the coefficients for rental terraced properties. The model reports that double glazing is significantly associated with an increase in WOZ value of 1.06 percent. Solar panels are found to be significantly associated with an increase of 1.91 percent in WOZ value.

Based on the estimation results in table 3, the association between energy efficient attributes and the WOZ value of a property appears to be dependent on the type of property and the type or tenure. The results show no similarities between the groups, which implies that the different groups have unique associations between energy efficient attributes and WOZ value.

[2] Due to the use of a semi-log model, the estimated coefficients are used in the following formula to be able to interpret the effect of the variable on the property value: [exp(*natural logarithm coefficient*) – 1] * 100 %

**Table 3.** Hedonic price model estimation results on WOZ value.

| | Owner-occupied | | | | Rental | | | |
|---|---|---|---|---|---|---|---|---|
| | Apartment | | Terraced | | Apartment | | Terraced | |
| Variables | (1) | | (2) | | (3) | | (4) | |
| **Energy efficient attributes** | | | | | | | | |
| Double glazing | -0.00965 | (0.0183) | -0.00975 | (0.0107) | 0.00313 | (0.00642) | 0.0105* | (0.00539) |
| Isolation | 0.00266 | (0.0239) | 0.00753 | (0.0115) | 0.0199** | (0.00892) | -0.00851 | (0.00623) |
| Solar panels | -0.0411 | (0.0499) | 0.0191 | (0.0150) | -0.0119 | (0.0127) | 0.0189** | (0.00815) |
| New central heating | -0.0318* | (0.0174) | -0.000470 | (0.00927) | 0.00942 | (0.00605) | 0.00170 | (0.00483) |
| Heat pump | -0.00570 | (0.0746) | 0.0695 | (0.0443) | 0.0571** | (0.0246) | -0.0202 | (0.0234) |
| City/district heating | -0.00781 | (0.0265) | -0.0283 | (0.0178) | -0.0149 | (0.0110) | -0.00392 | (0.0131) |
| **Property characteristics** | Yes | | Yes | | Yes | | Yes | |
| **Locational characteristics** | Yes | | Yes | | Yes | | Yes | |
| **Location fixed effects** | Yes | | Yes | | Yes | | Yes | |
| Constant | 11.07*** | (0.0642) | 10.84*** | (0.0777) | 10.88*** | (0.0335) | 10.79*** | (0.0364) |
| Observations | 1,127 | | 2,267 | | 7,191 | | 5,583 | |
| R-squared | 0.670 | | 0.668 | | 0.581 | | 0.658 | |

*Note*: Dependent variable is the natural logarithm of the WOZ value. Robust standard errors are noted between parentheses. Full estimation results are found in table 6 in Appendix A. *** p<0.01, ** p<0.05, * p<0.1

*5.1.1 Sensitivity analysis on the value of houses*

To explore possible differences in the association between energy efficient attributes and WOZ values or transaction prices, a similar hedonic pricing model was estimated using transaction prices as dependent variable. To ensure a true-to-value representation of historic transaction prices, the year fixed effects are added to the model. The WoON data on transaction prices exclusively contains transaction prices of owner-occupied properties, which limits the analysis to owner-occupied apartments and terraced properties. The estimation results of the hedonic pricing model based on transaction prices are presented in table 4.

Column 1 in table 4 reports no significant associations between energy efficient attributes and the transaction price of owner-occupied apartments, whereas a new central heating installation is found to be negatively associated with the WOZ value of owner-occupied properties (see column 1 in table 3). The results of owner-occupied terraced properties in column 2 of table 4 show that heat pumps are significantly associated with an increased transaction price of 11.07 percent. On the contrary, new central heating installations and city or district heating are significantly associated with a decrease in transaction price of, respectively, 2.25 percent and 4.15 percent. These findings suggest that there are differences in the association between energy efficient attributes and the two measures of property value.

**Table 4.** Hedonic price model estimation results on transaction price.

| | | Apartment | | Terraced | |
|---|---|---|---|---|---|
| Variable | | (1) | | (2) | |
| **Energy efficient attributes** | Double glazing | 0.00920 | (0.0224) | 0.00380 | (0.0139) |
| | Isolation | -0.0354 | (0.0278) | 0.000692 | (0.0157) |
| | Solar panels | -0.0476 | (0.0625) | -0.0300 | (0.0235) |
| | New central heating | 0.00601 | (0.0218) | -0.0228* | (0.0129) |
| | Heat pump | 0.0471 | (0.0578) | 0.105** | (0.0497) |
| | City/district heating | 0.00944 | (0.0334) | -0.0424** | (0.0216) |
| **Property characteristics** | | Yes | | Yes | |
| **Locational characteristics** | | Yes | | Yes | |
| **Location fixed effects** | | Yes | | Yes | |
| **Year fixed effects** | | Yes | | Yes | |
| **Constant** | | 10.02*** | (0.102) | 10.00*** | (0.117) |

| | | |
|---|---|---|
| Observations | 1,116 | 2,261 |
| R-squared | 0.637 | 0.690 |

*Note*: Dependent variable is the natural logarithm of the transaction price. Robust standard errors are noted between parentheses. Full estimation results are found in table 7 in Appendix A. *** p<0.01, ** p<0.05, * p<0.1

### 5.2 The impact of energy efficient attributes on residential satisfaction

To study the effect of energy efficient attributes on residential satisfaction, an ordered logistic regression model is estimated. Table 5 presents the odds ratio based on *residential satisfaction*, grouped in a similar manner as in section 5.1 based on the type of tenure and the type of property. The ordered logistic regression model includes energy efficient attributes, individual characteristics, household characteristics, property characteristics, and locational characteristics.

The results for homeowners in apartments are reported in column 1 in table 5. The significant association observed between isolation and residential satisfaction suggests that homeowners in apartments with isolation are 23.8 percent more likely to report a higher category of residential satisfaction than those without isolation. Column 2 in table 5 presents the findings of homeowners in terraced properties, where isolation and solar panels are found to be significantly associated with residential satisfaction. The findings suggest that homeowners in terraced properties with isolation or solar panels are, respectively, 17.3 percent or 23.7 percent more likely to report a higher category of residential satisfaction than those without these attributes. Column 3 in table 5 presents the findings on residential satisfaction of tenants in apartments. The findings show that double glazing, isolation and new central heating installations are significantly associated with their residential satisfaction. The presence of these attributes leads to an increased likelihood to report a higher category of residential satisfaction with 24.3 percent for double glazing, 28.7 percent for isolation and 14.5 percent for new central heating installations compared to tenants in apartments without these attributes. Looking at column 4 in table 5, the findings on tenants in terraced properties suggest that isolation and solar panels are significantly associated with residential satisfaction for this group. The likelihood for tenants in terraced properties to report a higher category of residential satisfaction increased by 68.5 percent when isolation is present and 36.1 percent when solar panels are present compared to the situation where these attributes are not present.

The findings suggest that isolation has an overall positive effect on the likelihood to report a higher category of residential satisfaction for homeowners and tenants in apartments and terraced properties, although there are large differences in the size of the effect between the groups. Solar panels are found to be associated with the residential satisfaction of homeowners and tenant in terraced properties, whereas this is not the case of residents of apartments. The findings show that there exist different associations between energy efficient attributes and residential satisfaction based on the type of property and the type of tenure.

**Table 5.** Ordered logistic regression results on residential satisfaction.

| | Homeowners | | | | Tenants | | | |
|---|---|---|---|---|---|---|---|---|
| | Apartment | | Terraced | | Apartment | | Terraced | |
| Variables | (1) | | (2) | | (3) | | (4) | |
| **Energy efficient attributes** | | | | | | | | |
| Double glazing | 0.918 | (0.0849) | 1.036 | (0.0516) | 1.243*** | (0.0719) | 1.026 | (0.0645) |
| Isolation | 1.238* | (0.138) | 1.173*** | (0.0655) | 1.287*** | (0.103) | 1.685*** | (0.125) |
| Solar panels | 1.466 | (0.372) | 1.237*** | (0.0952) | 1.166 | (0.153) | 1.361*** | (0.133) |
| New central heating | 0.887 | (0.0729) | 1.045 | (0.0460) | 1.145*** | (0.0576) | 1.091 | (0.0608) |
| Heat pump | 1.503 | (0.648) | 1.232 | (0.262) | 1.087 | (0.212) | 1.105 | (0.319) |
| City/district heating | 0.991 | (0.150) | 1.035 | (0.0978) | 1.126 | (0.0986) | 1.017 | (0.138) |
| **Individual characteristics** | Yes | | Yes | | Yes | | Yes | |
| **Household characteristics** | Yes | | Yes | | Yes | | Yes | |
| **Property characteristics** | Yes | | Yes | | Yes | | Yes | |
| **Locational characteristics** | Yes | | Yes | | Yes | | Yes | |
| Observations | 3,417 | | 10,895 | | 8,509 | | 6,241 | |
| Pseudo R-squared | 0.2063 | | 0.1494 | | 0.1487 | | 0.1342 | |

*Note*: Dependent variable is Residential Satisfaction. Standard errors are noted between parentheses. Full estimation results are found in table 8 in Appendix A. *** p<0.01, ** p<0.05, * p<0.1

# 6 Discussion

## 6.1 Energy efficient attributes and property prices

The purpose of the first part of this study is to gain insights into the relationship between energy efficient attributes and property values of Dutch residential property. The results suggest that energy efficient attributes in the current study have a significant association with WOZ value and transaction prices. However, this observation differs among groups in terms of the number of associated attributes, their size, and whether the association is positive or negative.

Previous studies identified solar technology (Hurst & Halvitigala, 2020), double glazing (Sayce & Wilkinson, 2019), and heat pumps (Vimpari, 2021) to be positively associated with property value. Although similar associations are observed in the current analysis, these observations remain limited to only one of the groups in the analysis. The positive association between solar technology, double glazing and property values as suggested in the literature (see Hurst & Halvitigala, 2020; Sayce & Wilkinson, 2019) are only verified for rental terraced properties and the positive association between heat pumps and property value (see Vimpari, 2021) is observed merely for rental apartments. The limited evidence on the effects of solar technology in owner-occupied properties could be influenced by the property market studied and the relating climate. Hurst & Halvitigala (2020) studied the Australian market, whereas the current analysis is focused on the Dutch market where the sun is less prominent in the climate. Furthermore, the limited findings on the association between double glazing in rental properties and the absence of such associations in owner-occupied properties do not verify the findings by Sayce & Wilkinson (2019) that double glazing shows to have the largest impact on property value in the EU. This findings may be the result of 'brown discounts', where the price of property without double glazing falls below the market mean rather than that it adds value, or due to the low capitalisation level of energy efficient attributes in the Dutch property market (see Sayce & Wilkinson, 2019). The positive association between heat pumps and property values confirms earlier findings by Vimpari (2021). Next to the positive association between heat pumps and property values, Vimpari (2021) found that heat pumps have a large potential to reduce energy consumption. Both financial incentives will play an increasingly larger role in the coming decade due to new Dutch legislation where heat pumps will be the next sustainable standard from 2026 onwards (Rijksoverheid, 2022). The legislation may cause lower demand for property with central heating in the coming years.

The limited association identified between energy efficient attributes and residential property values in the Netherlands may be the result of using WOZ value as a measure for property value. Whilst the WOZ value is based on a hypothetically fair market price for property in the market, not all energy efficient attributes are considered when determining the WOZ value. As a result, the WOZ value of properties may not provide a sufficiently accurate measure to observe statistically refined effects while there is an economically significant effect. Although municipalities have to include such attributes in determining the WOZ value, the owners of properties in the Netherland do not have to declare all of the refurbishments. Given the WOZ value is used to determine taxes, homeowners generally are not interested in declaring refurbishments which can increase the WOZ value. The municipality may only discover the refurbishments, such as the instalment of solar panels on the roof, based on aerial imagery or information from Funda, a Dutch property selling platform. The sensitivity analysis on transaction prices in table 4 showed some interesting differences compared to the WOZ value analysis in table 3. These findings imply that the type of measurement used for property values should be considered when studying the relationship between property value and energy efficient attributes.

## 6.2 Energy efficient attributes and residential satisfaction

The second analysis provides a better understanding of the relationship between residential satisfaction and energy efficient attributes. The results revealed that isolation has an overall positive effect on the likelihood for residents to report a higher category of residential satisfaction, while the findings on the other attributes were mixed.

The current body of literature describes that attributes which lead to energy efficiency, water efficiency, and improved indoor air quality have a positive effect on residential satisfaction. More specifically, Tan (2014b) found that solar panels, double glazing, LED lighting, ventilation, and heat insulation are important contributors. The positive associations between residential satisfaction and double glazing, isolation, solar panels and new central heating are partially consistent with earlier findings in the literature. The positive association between double glazing and residential satisfaction is only observed for tenants in apartments. This observations may be the result of homeowners and tenants in terraced properties  perceiving double glazing as a “golden standard” rather than an aspiration, as a similar phenomenon as brown discounts for property values (see Sayce & Wilkinson, 2019). Such a phenomenon may explain the insignificant findings on residential satisfaction. Moreover, a recent study by Stuart-Fox et al. (2019) showed that up to 19 percent of Dutch rental properties does not have double glazing compared to 7 percent of owner-occupied properties. As a result, the brown discounts may be more prevalent among homeowners than tenants, leading to the absence of significant associations between residential satisfaction of homeowners and double glazing. Another interesting observation is that solar panels seem to only affect the residential satisfaction of residents in terraced properties. Residents living in terraced properties are most often the only beneficiaries of the energy generated by solar panels, whilst residents living in apartments have to come to an agreement about the placement of solar panels with the owner’s association of the complex and the distribution of generated energy (De Heer et al., 2022). The indirect and collective nature of solar panels on an apartment complex may reduce the aspiration gap for solar panels, whilst other energy efficient attributes are perceived as more profitable for an apartment as property type (see Uidhir et al., 2020).

## 6.3 Comparing the monetary and non-monetary valuation of energy efficient attributes

The two analyses on property values and residential satisfaction are used to compare the monetary and non-monetary valuation of energy efficient attributes. Earlier research by Liu et al. (2019b) showed that there must be a willingness to pay for energy efficiency to be able to charge such a premium. The willingness to pay is generated if occupants experience sufficient levels of residential satisfaction. This study finds only very limited evidence for such a relationship. More specifically, isolation in rental apartments and solar panels on rental terraced properties are found to be significantly associated with both WOZ value and residential satisfaction. These findings suggest that residential satisfaction with energy efficient attributes generates a very limited willingness to pay for such attributes (see Liu et al., 2019b). Yet, the conclusion whether or not the significance of energy efficient attributes for residential satisfaction resembles the premiums charged for properties is not clearcut. Although an individual may be satisfied with an energy efficient attribute such as double glazing and unsatisfied with the heat pump, the heat pump may still be worth a higher value than the double glazing. Moreover, the energy efficient attribute an individual is satisfied with may be worth little to none as a result of brown discounts or low capitalisation levels such as observed in the Dutch residential market (see Sayce & Wilkinson, 2019). Such phenomena may not be captured in the model as proposed by Liu et al. (2019b), which could lead to biased interpretations of findings. Furthermore, financial incentives, such as loans for the investment in energy efficiency, may be necessary to overcome the gap between the willingness to pay and the costs of energy efficiency. Portnov et al. (2018) found that financial incentives may cause a decrease in the willingness to pay. The limited correspondence observed in terms of the association of energy efficient attributes with residential satisfaction and property values may have been subject to the effects of financial incentives. Despite that financial incentives on the Dutch property market often do not suffice to generate considerable progress (Vringer et al., 2016), the subsidies for, for example, solar panels may have had a decreasing effect on the willingness to pay, while residents remained satisfied with the solar panels. Although the current model was not able to elucidate whether the results were affected by this phenomenon, the results contribute to the literature by providing new insights into the comparison between the monetary and non-monetary valuations of energy efficiency.

## 6.4 Limitations and future recommendations

There exist some limitations regarding the current study design which should be considered. First, the use of data was limited to the WoON 2018 edition due to a delay in the 2021 edition and missing data on energy efficient attributes in earlier editions. It is recommended to perform similar studies when future editions of the data are available or when more comprehensive dataset which allow for timeseries analyses are available to observe trends and patterns throughout time. Second, the motives for investing in energy efficient attributes in housing are not included in the current study, although limited information is already available. Due to a very low number of observations in the WoON dataset, statistical analysis was not possible in the current study for these variables. However, analysis on the motivations may provide the opportunity to in-depth study the willingness to pay for energy efficient attributes and find how this affects the findings in the perspective of the current research design.

Future research could focus on several aspects revealed throughout the current study. First, the framework of willingness to pay, residential satisfaction and property values can be applied in the context of willingness to pay for additional rent when property is very energy efficient. Second, more work can be done on the actual motivation for energy efficiency to better understand the willingness to pay. Previous studies already showed that certain lifestyle choices have been important determinants for occupants' choices regarding housing. New insights may also elucidate the non-correspondence between residential satisfaction and property values observed during this study. Last, taking into account the financial benefits of lower energy costs as a result of energy efficient attributes in modelling willingness to pay and price premiums may provide a new perspective on the capitalisation of energy efficiency.

# 7 Conclusion

The present research aimed to clarify what the effect of energy efficient attributes is on the Dutch residential market in terms of the monetary and non-monetary valuation and how these valuations compare. Property values and residential satisfaction were quantitatively studied in a framework of willingness to pay by estimating a hedonic pricing model and an ordered logistic regression model. It was hypothesised that the monetary valuation of energy efficient attributes in terms of the property value premium corresponds with the non-monetary valuation in terms of residential satisfaction. The results showed that the energy efficient attributes associated with property values have limited correspondence to the attributes which positively impact residential satisfaction. Moreover, no correspondence was found when considering transaction prices. This finding suggests that the willingness to pay generated by residential satisfaction does only seem to induce a very limited ability to charge premiums for the relevant energy efficient attributes. The limited correspondence observed in the analysis may have been the result of factors like brown discounts, low capitalisation rates and financial incentives. This study added to the existing body of literature by providing a comparison of both types of valuation and a better understanding of the underlying assumption of willingness to pay for energy efficient attributes in housing.

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# Appendix A: Full estimation results

**Table 6.** Full estimation results hedonic price model on WOZ-value.

| | | **Owner-occupied** | | | | **Rental** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Apartment | | Terraced | | Apartment | | Terraced | |
| Variables | | (1) | | (2) | | (3) | | (4) | |
| **Energy efficient attributes** | | | | | | | | | |
| | Double glazing | -0.00965 | (0.0183) | -0.00975 | (0.0107) | 0.00313 | (0.00642) | 0.0105* | (0.00539) |
| | Isolation | 0.00266 | (0.0239) | 0.00753 | (0.0115) | 0.0199** | (0.00892) | -0.00851 | (0.00623) |
| | Solar panels | -0.0411 | (0.0499) | 0.0191 | (0.0150) | -0.0119 | (0.0127) | 0.0189** | (0.00815) |
| | New central heating | -0.0318* | (0.0174) | -0.000470 | (0.00927) | 0.00942 | (0.00605) | 0.00170 | (0.00483) |
| | Heat pump | -0.00570 | (0.0746) | 0.0695 | (0.0443) | 0.0571** | (0.0246) | -0.0202 | (0.0234) |
| | City/district heating | -0.00781 | (0.0265) | -0.0283 | (0.0178) | -0.0149 | (0.0110) | -0.00392 | (0.0131) |
| **Number of rooms** | | 0.0170* | (0.00904) | 0.0376*** | (0.00530) | 0.0272*** | (0.00482) | 0.0330*** | (0.00346) |
| **Surface area property** | | 0.00706*** | (0.000436) | 0.00470*** | (0.000246) | 0.00658*** | (0.000283) | 0.00364*** | (0.000188) |
| **Surface area living room** | | 0.00141*** | (0.000325) | 0.000926*** | (0.000258) | 0.000985*** | (0.000168) | 0.000474*** | (0.000162) |
| **Building year** | 1945 – 1959 | -0.283*** | (0.0320) | -0.123*** | (0.0217) | -0.197*** | (0.0182) | 0.00732 | (0.0133) |
| 'Before 1945' as | 1960 – 1969 | -0.324*** | (0.0278) | -0.134*** | (0.0176) | -0.185*** | (0.0171) | 0.0147 | (0.0129) |
| base | 1970 – 1979 | -0.325*** | (0.0318) | -0.148*** | (0.0178) | -0.152*** | (0.0174) | 0.0267** | (0.0133) |
| | 1980 – 1989 | -0.220*** | (0.0318) | -0.0939*** | (0.0171) | -0.0856*** | (0.0174) | 0.0608*** | (0.0130) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1990 – 1999 | -0.0330 | (0.0333) | 0.00943 | (0.0187) | 0.0194 | (0.0182) | 0.146*** | (0.0139) |
| | 2000 - 2009 | -0.0305 | (0.0336) | 0.0323 | (0.0207) | 0.145*** | (0.0190) | 0.211*** | (0.0162) |
| | 2010 and later | 0.0435 | (0.0412) | 0.0770*** | (0.0214) | 0.157*** | (0.0221) | 0.246*** | (0.0188) |
| **Outside area** | Balcony | 0.0239 | (0.0272) | 0.0696*** | (0.0136) | 0.0165 | (0.0103) | 0.0326*** | (0.0120) |
| ‘No’ as base | Garden | 0.0561** | (0.0277) | 0.0220 | (0.0343) | 0.0238** | (0.0109) | 0.0590*** | (0.0184) |
| | Patio | 0.0166 | (0.0460) | 0.0155 | (0.0441) | 0.0413* | (0.0215) | 0.00506 | (0.0318) |
| | Courtyard | -0.0210 | (0.0357) | -0.0186 | (0.0336) | 0.00883 | (0.0174) | -0.0160 | (0.0162) |
| | Surrounding parcel | 0.0423 | (0.0386) | 0.0506** | (0.0248) | -0.0135 | (0.0554) | 0.0108 | (0.0171) |
| **Type of parking** | Own parking | 0.0330 | (0.0240) | 0.0267** | (0.0126) | 0.00712 | (0.0107) | 0.0397*** | (0.00732) |
| ‘No parking’ as base | Shared parking lot | -0.00228 | (0.0155) | -0.0128 | (0.00866) | -0.00466 | (0.00566) | 0.000610 | (0.00472) |
| **Distance to supermarket** | | -4.65e-05** | (1.86e-05) | -1.08e-05 | (9.09e-06) | -1.16e-05 | (7.61e-06) | -5.37e-06 | (4.93e-06) |
| **Distance to highway** | | 1.21e-05 | (8.95e-06) | 3.65e-06 | (5.65e-06) | -5.87e-07 | (3.46e-06) | -8.58e-06*** | (2.84e-06) |
| **Urbanity** | Middle | 0.00299 | (0.0367) | 0.00143 | (0.0127) | 0.0229** | (0.0111) | -0.0117* | (0.00693) |
| ‘Low’ as base | High | -0.0252 | (0.0294) | 0.0369*** | (0.0111) | 0.0226** | (0.00990) | 0.0289*** | (0.00628) |
| **Location fixed effects** | | YES | | YES | | YES | | YES | |
| **Constant** | | 11.07*** | (0.0642) | 10.84*** | (0.0777) | 10.88*** | (0.0335) | 10.79*** | (0.0364) |
| Observations | | 1,127 | | 2,267 | | 7,191 | | 5,583 | |
| R-squared | | 0.670 | | 0.668 | | 0.581 | | 0.658 | |

*** p<0.01, ** p<0.05, * p<0.1

**Table 7.** Full estimation results hedonic price model on transaction price.

| | | Apartment | | Terraced | |
|---|---|---|---|---|---|
| Variables | | (1) | | (2) | |
| **Energy efficient attributes** | | | | | |
| | Double glazing | 0.00920 | (0.0224) | 0.00380 | (0.0139) |
| | Isolation | -0.0354 | (0.0278) | 0.000692 | (0.0157) |
| | Solar panels | -0.0476 | (0.0625) | -0.0300 | (0.0235) |
| | New central heating | 0.00601 | (0.0218) | -0.0228* | (0.0129) |
| | Heat pump | 0.0471 | (0.0578) | 0.105** | (0.0497) |
| | City/district heating | 0.00944 | (0.0334) | -0.0424** | (0.0216) |
| **Number of rooms** | | 0.0221* | (0.0116) | 0.0402*** | (0.00683) |
| **Surface area property** | | 0.00595*** | (0.000573) | 0.00377*** | (0.000358) |
| **Surface area living room** | | 0.00113*** | (0.000377) | 0.00151*** | (0.000347) |
| **Building year** | 1945 – 1959 | -0.223*** | (0.0349) | -0.104*** | (0.0277) |
| ‘Before 1945’ as | 1960 – 1969 | -0.307*** | (0.0335) | -0.124*** | (0.0252) |
| base | 1970 – 1979 | -0.311*** | (0.0391) | -0.108*** | (0.0255) |
| | 1980 – 1989 | -0.186*** | (0.0379) | -0.0726*** | (0.0239) |
| | 1990 – 1999 | -0.00794 | (0.0437) | 0.0141 | (0.0255) |

| | | | | | |
|---|---|---|---|---|---|
| | 2000 - 2009 | -0.00613 | (0.0388) | 0.0848*** | (0.0280) |
| | 2010 and later | 0.0548 | (0.0456) | 0.0893*** | (0.0268) |
| | | | | | |
| **Outside area** | Balcony | 0.0151 | (0.0320) | 0.0647*** | (0.0176) |
| ‘No’ as base | Garden | 0.0735** | (0.0329) | -0.0220 | (0.0381) |
| | Patio | 0.0775* | (0.0428) | 0.0131 | (0.0472) |
| | Courtyard | -0.00402 | (0.0412) | -0.0783 | (0.0484) |
| | Surrounding parcel | 0.0488 | (0.0561) | 0.0580 | (0.0421) |
| | | | | | |
| **Type of parking** | Own parking | 0.0308 | (0.0318) | 0.0247 | (0.0151) |
| ‘No parking’ as base | Shared parking lot | -0.00395 | (0.0195) | -0.00691 | (0.0126) |
| **Distance to supermarket** | | -7.11e-05*** | (2.21e-05) | 3.82e-06 | (1.20e-05) |
| | | | | | |
| **Distance to highway** | | 8.53e-06 | (1.18e-05) | 1.73e-05** | (7.32e-06) |
| | | | | | |
| **Urbanity** | Middle | -0.00456 | (0.0411) | 0.00460 | (0.0177) |
| ‘Low’ as base | High | -0.0509 | (0.0344) | 0.0169 | (0.0158) |
| | | | | | |
| **Location fixed effects** | | YES | | YES | |
| **Year fixed effects** | | YES | | YES | |
| | | | | | |
| **Constant** | | 10.02*** | (0.102) | 10.00*** | (0.117) |
| | | | | | |
| Observations | | 1,116 | | 2,261 | |
| R-squared | | 0.637 | | 0.690 | |

*** p<0.01, ** p<0.05, * p<0.1

**Table 8.** Full estimation results ordered logistic regression on residential satisfaction with pooled and separate models.

| | | Owner-occupied | | | | Rental | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Apartment | | Terraced | | Apartment | | Terraced | |
| Variables | | (1) | | (2) | | (3) | | (4) | |
| **Energy efficient attributes** | | | | | | | | | |
| | Double glazing | 0.918 | (0.0849) | 1.036 | (0.0516) | 1.243*** | (0.0719) | 1.026 | (0.0645) |
| | Isolation | 1.238* | (0.138) | 1.173*** | (0.0655) | 1.287*** | (0.103) | 1.685*** | (0.125) |
| | Solar panels | 1.466 | (0.372) | 1.237*** | (0.0952) | 1.166 | (0.153) | 1.361*** | (0.133) |
| | New central heating | 0.887 | (0.0729) | 1.045 | (0.0460) | 1.145*** | (0.0576) | 1.091 | (0.0608) |
| | Heat pump | 1.503 | (0.648) | 1.232 | (0.262) | 1.087 | (0.212) | 1.105 | (0.319) |
| | City/district heating | 0.991 | (0.150) | 1.035 | (0.0978) | 1.126 | (0.0986) | 1.017 | (0.138) |
| **Age respondent** | | | | | | | | | |
| ’17-24 years’ as base | 25 – 34 years | 1.175 | (0.285) | 0.686* | (0.145) | 0.631*** | (0.0696) | 0.713 | (0.172) |
| | 35 – 44 years | 1.016 | (0.252) | 0.716 | (0.152) | 0.665*** | (0.0808) | 0.607** | (0.147) |
| | 45 – 54 years | 1.367 | (0.343) | 0.938 | (0.199) | 0.723*** | (0.0873) | 0.768 | (0.184) |
| | 55 – 64 years | 1.935*** | (0.488) | 1.252 | (0.267) | 0.734** | (0.0882) | 0.938 | (0.224) |
| | 65 – 74 years | 2.054*** | (0.521) | 1.389 | (0.302) | 0.961 | (0.116) | 1.062 | (0.254) |
| | 75 years and older | 2.892*** | (0.782) | 2.010*** | (0.469) | 1.634*** | (0.199) | 1.915*** | (0.468) |
| **Ethnicity respondent** | | | | | | | | | |
| ‘Autochthonous’ | Non-western | 0.732** | (0.103) | 0.807** | (0.0766) | 0.607*** | (0.0413) | 0.584*** | (0.0544) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| as base | Western | 0.804* | (0.0957) | 0.764*** | (0.0566) | 0.882* | (0.0600) | 0.784*** | (0.0659) |
| **Education respondent** | | | | | | | | | |
| ‘Low’ as base | Middle | 0.916 | (0.0961) | 0.872** | (0.0483) | 0.993 | (0.0547) | 1.063 | (0.0642) |
| | High | 0.863 | (0.0923) | 0.846*** | (0.0491) | 1.039 | (0.0647) | 1.109 | (0.0864) |
| **Health respondent** | | | | | | | | | |
| ‘Very bad’ as base | Bad | 0.972 | (0.285) | 1.016 | (0.181) | 1.105 | (0.113) | 1.032 | (0.130) |
| | Neutral | 1.002 | (0.266) | 1.015 | (0.163) | 1.235** | (0.118) | 1.201 | (0.141) |
| | Good | 1.245 | (0.316) | 1.384** | (0.211) | 1.552*** | (0.140) | 1.703*** | (0.189) |
| | Very good | 2.494*** | (0.661) | 2.198*** | (0.347) | 2.185*** | (0.228) | 2.045*** | (0.266) |
| **Household composition** | | | | | | | | | |
| ‘One-person’ as base | Couple | 0.876 | (0.124) | 1.035 | (0.0749) | 0.907 | (0.0721) | 0.882 | (0.0815) |
| | Couple with child | 0.447*** | (0.0926) | 0.609*** | (0.0630) | 0.489*** | (0.0647) | 0.724** | (0.0979) |
| | Single-parent | 0.447*** | (0.0900) | 0.684*** | (0.0748) | 0.652*** | (0.0709) | 0.637*** | (0.0722) |
| **Household income** | | 1.000** | (1.36e-06) | 1.000 | (6.48e-07) | 1.000 | (1.03e-06) | 1.000** | (1.59e-06) |
| **Housing expenses** | | 1.000 | (0.000140) | 1.000*** | (7.53e-05) | 1.000 | (0.000114) | 1.000* | (0.000163) |
| **Number of rooms** | | 1.031 | (0.0600) | 1.035 | (0.0283) | 1.084** | (0.0413) | 0.977 | (0.0381) |
| **Surface area property** | | 1.009*** | (0.00179) | 1.004*** | (0.000963) | 1.003*** | (0.00116) | 1.003** | (0.00137) |
| **Ratio rooms – people** | | 1.037 | (0.135) | 0.970 | (0.0674) | 1.157** | (0.0833) | 1.073 | (0.0915) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Building year** | | | | | | | | | |
| 'Before 1945' as base | 1945 – 1959 | 0.765** | (0.104) | 0.941 | (0.0894) | 0.748*** | (0.0669) | 0.972 | (0.107) |
| | 1960 – 1969 | 0.822 | (0.106) | 0.974 | (0.0760) | 0.997 | (0.0826) | 1.104 | (0.119) |
| | 1970 – 1979 | 0.911 | (0.133) | 0.898 | (0.0652) | 1.179* | (0.0991) | 1.235** | (0.132) |
| | 1980 – 1989 | 0.908 | (0.134) | 1.104 | (0.0801) | 1.232*** | (0.0982) | 1.414*** | (0.150) |
| | 1990 – 1999 | 1.757*** | (0.261) | 1.237*** | (0.101) | 1.403*** | (0.129) | 2.086*** | (0.271) |
| | 2000 - 2009 | 1.975*** | (0.313) | 1.704*** | (0.163) | 2.272*** | (0.231) | 2.799*** | (0.418) |
| | 2010 and later | 3.174*** | (0.680) | 2.977*** | (0.322) | 3.067*** | (0.354) | 7.817*** | (1.249) |
| **Type of parking** | | | | | | | | | |
| 'No parking' as base | Own parking | 0.995 | (0.131) | 1.081 | (0.0675) | 1.211** | (0.110) | 1.008 | (0.0892) |
| | Shared parking lot | 1.064 | (0.0940) | 1.023 | (0.0475) | 1.118** | (0.0527) | 0.919 | (0.0499) |
| **Neighbourhood satisfaction** | | | | | | | | | |
| 'Very dissatisfied' as base | Dissatisfied | 0.0425*** | (0.0162) | 0.0473*** | (0.0121) | 0.0590*** | (0.00900) | 0.0818*** | (0.0157) |
| | Neutral | 0.0538*** | (0.0113) | 0.0776*** | (0.0108) | 0.142*** | (0.0147) | 0.169*** | (0.0221) |
| | Satisfied | 0.0983*** | (0.0144) | 0.141*** | (0.0118) | 0.186*** | (0.0148) | 0.173*** | (0.0167) |
| | Very satisfied | 0.275*** | (0.0253) | 0.283*** | (0.0137) | 0.369*** | (0.0219) | 0.348*** | (0.0248) |
| **Neighbourhood cohesion** | | 1.269*** | (0.0351) | 1.266*** | (0.0203) | 1.254*** | (0.0186) | 1.268*** | (0.0224) |
| **Urbanity** | | | | | | | | | |
| 'Low' as base | Middle | 1.048 | (0.186) | 1.144** | (0.0719) | 1.057 | (0.0884) | 1.158** | (0.0832) |
| | High | 1.318* | (0.194) | 1.262*** | (0.0695) | 1.129* | (0.0753) | 1.260*** | (0.0775) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Cut 1 | 0.0296*** | (0.0164) | 0.00539*** | (0.00228) | 0.0655*** | (0.0159) | 0.0377*** | (0.0142) |
| Cut 2 | 0.123*** | (0.0653) | 0.0383*** | (0.0139) | 0.305*** | (0.0723) | 0.163*** | (0.0602) |
| Cut 3 | 0.764 | (0.401) | 0.335*** | (0.118) | 1.574* | (0.372) | 0.993 | (0.366) |
| Cut 4 | 21.00*** | (11.08) | 10.67*** | (3.771) | 27.62*** | (6.591) | 19.24*** | (7.126) |
| | | | | | | | | |
| Observations | 3,417 | | 10,895 | | 8,509 | | 6,241 | |
| Pseudo R-squared | 0.2063 | | 0.1494 | | 0.1487 | | 0.1342 | |

*** p<0.01, ** p<0.05, * p<0.1