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Chapter 26
The Total Cost of Living in Relation to Energy Efficiency Upgrades in the Dutch, Multi-Residential Building Stock

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Abstract Decarbonizing the housing stock is one of the largest challenges in the built environment today, and is getting attention not only from policymakers, but also from social housing corporations, financial and tenants' organisations. In line with the international Paris-Climate-Change-Conference 2015, Dutch cities and housing associations have embraced this challenge with the ambitions to become carbon neutral in 2050. To reach such ambitious goals, both the rate and depth of renovation need to increase significantly. In the Netherlands, the Energy Agreement for Sustainable Growth, indicates that 300.000 dwellings have to be renovated annually, in accordance with the Energy Performance of Buildings Directive adopted by the European Union, to improve the Dutch building stock towards energy neutrality. Several technical solutions to eliminate the energy demand in dwelling have been developed and tested. Nevertheless, the intake rate of deep retrofitting is low. Currently, most improvements in residential buildings consist of basic maintenance and shallow renovation, but broader or deeper energy renovation measures are required. Despite more recent developments, there are still significant barriers related to financing, lack of information, and user acceptance. Complex technical characteristics are not always taken into account by tenants; the focus is usually on the ease of use, comfort and living expenses.

To this end, the present study sets of to investigate the relationship between energy efficiency upgrade measures and cost of living. Focusing on the post-war, multi-family social housing in the Netherlands, a framework of refurbishment measures that affect the energy efficiency were identified, and their performance was simulated. The variations refer to the façade design, thermal envelope upgrade, winter-garden addition and reviewable energy. The energy efficiency indicator is the

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energy cost reduction, as well as the carbon footprint of the energy use. Furthermore, the rental price adjustment was estimated, taking into account the refurbishment investment and the operation cost of the renovated dwellings. All tested combination of variables resulted in significant energy savings, up to 70%, while energy generation was proven to be cost-effective, as it has a considerable positive effect on the energy use and the energy cost, without increasing the rental price.

The results aim at supporting the decision-making discussion between the stakeholders, primarily housing associations and tenants. The relation between the energy consumption and rental price for the different options identifies the effect of design variation and demonstrated the attractive solutions that the tenants are more likely to accept, taking into account the overall cost of living and sustainability benefits.

Keywords Energy efficiency · Renovation · Cost of living

26.1 Introduction

Decarbonising the housing stock is one of the largest challenges in the built environment today, which is getting the attention not only from policymakers but also from social housing associations and other institutional real estate owners, financial organisations and users. Several studies (BPIE 2011, 2013; Crawford et al. 2014; IEAAnnex56 2012) have reported that huge potential for energy savings, improved health and comfort of the occupants', elimination of fuel poverty, and job creation lay in the technical upgrade of the existing buildings stock. In line with the international Paris-Climate-Change-Conference 2015, Dutch cities and housing associations have embraced this challenge with the ambitions to become carbon neutral in 2050.

To reach such ambitions, both the rate and depth of renovation need to significantly increase (Artola et al. 2016; BPIE 2011). In the Netherlands, the Energy Agreement for Sustainable Growth, indicates that 300.000 dwellings have to be renovated annually, in accordance with the Energy Performance of Buildings Directive adopted by the European Union, to improve the Dutch building stock to energy neutrality (DIRECTIVE 2010/31/ EU). Moreover, in the Netherlands, the housing associations have the ambition to achieve a carbon-neutral building stock by 2050 (AEDES 2017). A number of technical solutions to eliminate the energy demand in dwelling have been developed and tested. Those solution target different levels of energy efficiency, ranging from a small upgrade of the energy label, most commonly up to label B, to achieving zero-energy demand.

Nevertheless, the intake rate of deep retrofitting is low. Currently, most improvements in residential buildings consist of basic maintenance and shallow renovation, but broader or deeper energy renovation measures are required (Filippidou et al. 2016). Despite more recent developments, there are still significant barriers related to financing, lack of information, and user acceptance (Matschoss et al. 2013). The residents of the dwellings care less about the technical characteristics of a dwelling, but more about the use, comfort and living expenses.

To this end, the present study sets of to investigate the relationship between energy efficiency upgrade measures and cost of living. Focusing on the multi-family social housing in the Netherlands, a framework of refurbishment measures that affect the energy efficiency were identifies and their performance was calculated. The energy efficiency indicator is the energy cost, as well as the energy use. Furthermore, the rental price adjustment was estimated, taking into account the refurbishment investment and the exploitation cost of the renovated dwellings. The comparison of the energy use and rental price for the different options demonstrated the most attractive solutions that the tenants are more likely to accept, taking into account the overall cost of living and sustainability benefits. The results aim at supporting the decision-making discussion between the stakeholders, primarily housing associations and tenants.

26.2 Methodology

To provide insights into the study's question on the relation between energy saving renovation and cost of living, the evaluation of the refurbishment options is based on Key Performance Indicators (KPI's). The key performance indicator is a measurable value that demonstrates how effectively a system, in this case, the refurbished buildings, performs. The KPI's used in this study- as concluded out of focus groups with stakeholders, such as residents and housing associations- are the energy use and its resulting cost, the rent price, because it reflects the refurbishment costs as it will be explained in sect. 2.3, and the total cost of living, as the sum of energy cost and rent. The sustainability of the solutions is indicated by the energy demand since the same heating system, and fuel is applied to all options. Hence, the energy demand and CO2 emissions are proportional.

The steps to quantify the KPIs are hence related to the strategic organisation of the refurbishment measures, for starters, and then quantifying their effect on energy use, cost and rent price. The investigation is based on applying and refurbishment strategies on a case-study building. The specifics of the building were taken into account for the design and assumptions considered for the energy and cost calculations. The study focuses on low-rise, multi-family, walk-up apartments, as they present considerable challenges for their energy upgrade. Currently, there are still 799.956 apartments of all types from the period 1906–1965 in The Netherlands, 400.000 apartments of which are located in the four major cities. The building shown in Fig. 26.1 was selected as a case study to apply the refurbishment options, as being a typical example of the post-war period (Platform31 2013).

Fig. 26.1 Case study building: Camera Obscura, Overvecht Utrecht, 2016

26.2.1 Define the Alternatives and the Combinations: General Transformation Framework

In order to be able to evaluate the solution, the alternative refurbishment measures need to be defined. The measures are defined per category and per function, creating a "General Transformation Framework". The parameters taken into account for the framework development came out of research the existing tenement building types of the inter-war and post-war period and their special characteristics and projects (Oorschot et al. 2018).

Moreover, analysis of realised refurbishment project and interviews with architects and housing association helped to define the state-of-the-art. In the scope of the present study, the measures discussed refer to a cluster of technical interventions that can be employed to improve the energy efficiency of the apartments. Additional socio-cultural interventions related to the functional and cultural heritage qualities are possible to be applied, but outside the present paper's scope.

As they are not likely to be applied individually, they have been combined into integrated solutions, before they can be evaluated regarding energy demand and cost. The alternative measures were defined based on analysis of current refurbishment practice, literature review and discussions with stakeholders. The aspects considered that have an impact on the energy use of the building are the following, as presented in below (Table 26.1):

26.2.2 Energy Demand Calculation and Indicators

For the refurbishment options to be evaluated and for the total cost of living to be calculated, the energy performance of the case-study building is estimated. Firstly, the energy use for both building and user-related sources is calculated using dynamic thermal performance simulation. Then, the energy use is simulated after the proposed, combined solutions have been applied. The software used for the thermal

Table 26.1 Overview of the alternative refurbishment solutions proposed

Aspects	Alternative		Description
Façade design	Existing		Existing façade design. Sill height 1 m. window-to-wall ratio 80%, operable 30%
	Half open		Half open facade with operable opaque ventilation openings, with respect of the most characteristic heritage elements. Window-to-wall ratio 60%, operable 0%
	Open		Open facade with glass from floor to floor, with respect of the most characteristic heritage elements. Window- to-wall ratio 100%, operable 50%
Thermal properties upgrade	Level B	Basic upgrade	Facade U = 0,20 W/m2K
			Roof U = 0,20 W/m2K
			Floor U = 0,28 W/m2K
			Windows double glazing / U = 1,2 W/m2K
	Level A	Advanced, towards ZEB standards	Facade U = 0,20 W/m2K
			Roof U = 0,15W/m2K
			Floor U = 0,25 W/m2K
			Windows triple glazing / U = 0,8 W/m2K
Extension	Winter-garden		Extension with a glass covered balcony.
			External wall: 100% glass Single.Open 80% at 24oC. Shading intern drapes
			Interior partition: Double glazing, 100%. Open 80%. Min temp for Nat vent 24oC
	No extension	No additional construction.	
Renewable energy generation	None	No PV panels nor solar collectors	
	PV	Calculated per apartment, based on the overall available area for PV application. Efficiency 255Wp	
	PV + solar collectors	Solar collectors are assumed to be placed on the balcony, on the south side, producing up to 330kWh/m2, which covers the energy demand for hot water	

simulation is DesignBuilder, which was chosen as appropriate for the purpose of this study because it can generate a range of environmental performance data such as energy consumption and internal comfort data. The actual data for the building's size and construction were used, data for the location climate were input, and occupancy data were based on the building's function, classified as "Tailored rating", according to European Standards EN15603 (2008).

26.2.3 Inputs

For every energy consumption calculation, the way the building is constructed and operated needs to be specified, as input. When comparing current and new energy demand, an assumption is that the usage patterns will not change significantly. A nuclear family (four-person household, two parents and two children) will be considered, as it is the largest percentage in the demographics of the case study. The different inputs are summarised in Table 26.2.

26.2.4 Comfort, Energy Demand, Energy Cost and Carbon Footprint

The simulation resulted in the amount of energy in kWh a dwelling requires per year, including HVAC systems, domestic hot water and appliances. Moreover, the internal temperatures were checked to calibrate the dwelling function and comfort, existing and refurbished, and ensure that overheating is avoided. The energy costs are based on the prices indicated there, considering fixed amounts for the grid, as well as different prices for peak hours, the following costs were calculated for electricity 0,18/ kWh and gas 0,77/ m3, including tax (Eurostat 2016). Those prices are then implemented to the simulation results, for electricity and gas demand respectively.

26.2.5 Total Cost of Living Calculation Method

The refurbishment strategies are evaluated regarding the effect the investment has on the rent price. To this end, a Life Cycle Costing (LCC) was performed. The increase in the rent price was based on the assumption that for sustainable housing to be financially feasible, all investments must be covered by the exploitation period rent income. Firstly, the investment costs of major renovations were determined without

Table 26.2 Energy simulation inputs

Parameter	Inputs
Location	Netherlands
Orientation	Depending on the specific building
Geometry and zones	Every room as a different zone, depending on activity (bedroom, living room etc.)
Occupancy	Based on zones function, for a four-person household
Openings	Layout: Building design. WWR between 60-100%
Heating/ DHW	Gas boiler, efficiency 80%
Ventilation	Natural inlet through windows/ mechanical outlet through bathroom and kitchen.

considering specific energy-saving measures. The investment costs have been defined according to the Dutch standard NEN 2699 (NEN 2017) as: the value in use of the existing building + the construction costs of the renovation + the additional costs such as fees, connection costs and taxes. The construction costs of all renovation measures have been estimated by EcoQuaestor (2014) cost database. As a result, the cost level of the budgets is consistent with Dutch building practice. The rent of the apartments after renovation but without specific energy-saving measures was determined by the "Appropriate allocation" scheme under the 2015 Housing Act. Subsequently, the investment costs of specific energy-saving measures are added to the initial investment.

The investment for both scenarios, with and without energy efficiency measures, is then included in a cash flow survey of operating costs and benefits according to the life-cycle costing (LCC) model of the NEN 2699 standard. The cost of maintenance, management costs and other property expenses are included. On the revenue side of the balance sheet, the present value of rental income was added, for an exploitation period, assuming 30 years is the exploitation period for an apartment in the social housing sector. In the renovation scenario, the extra investment costs of the specific measures were included in the cash flow analysis. The present value of the rental income was adjusted to close the balance. The increase in monthly rent was then calculated as the difference required to balance the cost and income in the LLC.

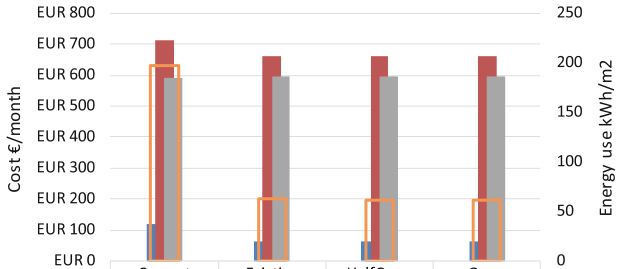
It needs to be clarified that this method can result in differences in the rent price for the same combinations of energy efficiency measures combinations. The reason for this discrepancy is that the rent after renovation, which also depends in other parameters, such as the additional number of rooms, or the construction of additional dwellings, which are not within the scope of the current study.

26.3 The Resulting Cost of Living for the Different Aspects

This section presents the effect of each aspect, as defined in Table 26.1, on the KPI's energy demand, energy cost, CO2, rent price and total cost of living. Not all KPI's are discussed in every case, depending on the significance of the effect. The numbers presented in the figures are based on averages values for the combination of measures that include the respective variations. These averages are the reason why the total cost of ownership is not always the sum of the average energy cost and the average rent in the following figures.

26.3.1 Façade Design

There were three different options for the façade design. Those options differ in the window- to-wall ratio (WWR), layout and operation. The design of the façade is important for how the building is perceived, and our proposals came out of the



	Current	Existing	HalfOpen	Open
Average of Energy cost €/month	121	63	62	62
Average of Total cost of living €/month	711	659	660	660
Average of Rent €/month	590	596	598	598
Average of Energy use kWh/m2	197	63	61	61

Fig. 26.2 Comparison of the Façade design variations and the current building, in terms of energy cost, rent, the total cost of living and energy use

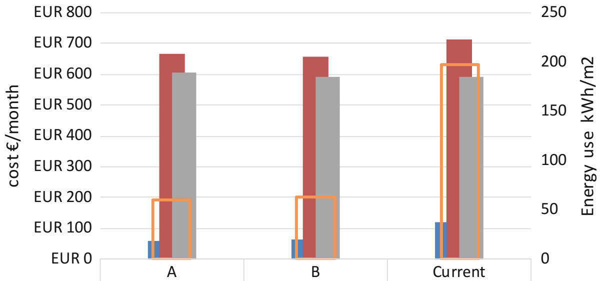
analysis of the building characteristics and discussions with architects and housing associations.

Comparing the performance of the three façade designs, however, we can see that energy demand and, hence the energy cost, does not differ significantly, as shown in Fig. 26.2. This similarity can be explained by the thermal properties of the different options, which are all upgraded to high thermal resistance. It is also the reason why there is a 50% reduction in the energy costs and 68% reduction in the energy demand, compared with the current building. Moreover, the WWR is all three variations are relatively high, ranging between 60% and 100%. Therefore, the heat losses from the glazing, as well as solar heat gains are similar, resulting in similar energy use in the refurbished apartments. The choice of high WWR is consistent with heritage values of the existing building design.

Finally, the investment for the new façade, and the resulting rent increase is also similar, with the option of preserving the existing façade layout being marginally more economical. Nevertheless, the total cost of living is lower by 7%.

26.3.2 Thermal Properties Upgrade

The building envelope is upgraded with the application of insulation on the façade and roof, as well as replacement of the windows. The basic upgrade (B) is the minimum required by the regulations in the Netherlands, while the second option (A) is going towards zero energy standards. The main difference between the two options is the glazing and the higher thermal resistance of the roof. As can be seen in Fig. 26.3, the difference in the energy demand between the two variations is 5%, which is marginal. The marginal difference can be interpreted by the already good thermal performance of the basic upgrade. However, the investment for the more



	A	B	Current
Average of Energy cost €/month	61	63	121
Average of Total cost of living €/month	665	655	711
Average of Rent €/month	603	592	590
Average of Energy use kWh/m2	60	63	197

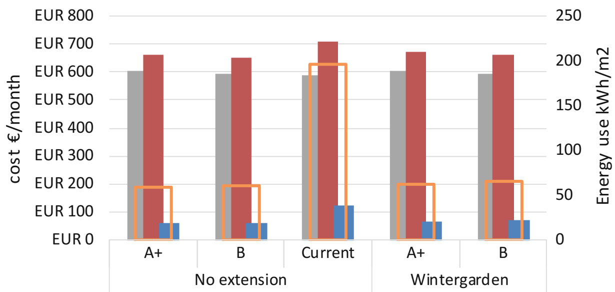
Fig. 26.3 Comparison of the thermal properties upgrade options and the current building, in terms of energy

advanced upgrade has resulted in a rent increase greater than the energy cost savings. In thissense, the cost-effectiveness of the basic upgrade is better. It needs to be noted, that in both cases the saving to the current energy use is significant, as already mentioned.

26.3.3 Extension

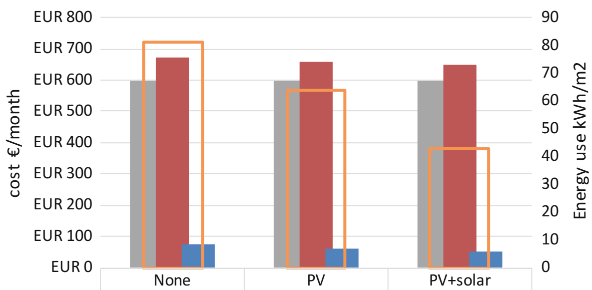
The option to extend the living space is beneficial for improving the living conditions and functionality of the dwellings. Such examples range from the cladding of existing balconies to new construction. For the present study, the option considered included an additional construction, with mostly glazed external wall, having as a reference the project Tour Bois-le-Prêtre by Druot, Lacaton & Vassal. The new living space is not conditioned. Hence, the interior partition, previously external wall, featured insulated windows. Both interior and exterior windows are operable.

Figure 26.4 presents an overview of the KPI's with and without the extension construction, in relation with the thermal envelope upgrade. One of the first conclusions is that this investment does not affect the rent increase, as the average rent is the same. However, the energy use is higher in the dwellings with the winter garden. The higher energy use can be explained by the additional living spaces, which are not conditioned. The total cost of living in all cases is lower than in the current building.



	No extension			Wintergarden	
	A+	B	Current	A+	B
Average of Rent €/month	603	592	590	603	592
Average of Total cost of living €/month	661	651	711	671	662
Average of Energy cost €/month	58	59	121	68	70
Average of Energy use kWh/m2	58	61	197	63	66

Fig. 26.4 Comparison of the winter garden extension in relation to the thermal properties upgrades, in terms of energy cost, rent, the total cost of living and energy use



	None	PV	PV+solar
Average of Rent €/month	597	598	597
Average of Total cost of living €/month	673	658	648
Average of Energy cost €/month	77	60	51
Average of Energy use (kWh/m2)	81	64	43

Fig. 26.5 Comparison of the thermal properties upgrade options and the current building, in terms of energy cost, rent, the total cost of living and energy use

26.3.4 Renewable Energy

Energy generation is a necessary step in the ambition to achieve energy neutrality on building level, and it is also a common consideration in energy efficiency upgrades. As shown in the results in Fig. 26.5, the application of renewable energy production technology can cut almost in.

half the energy use and 1/3 the energy cost. The rent, on the other hand, is not affected by the initial investment.

26.4 Discussion and Conclusion

The current paper described a methodology to combine the cost and the savings of energy efficiency upgrades in dwellings' refurbishment and identify the effect of design variation. Based on the aspects evaluated, the following main conclusions can be drawn.

- All tested combination of variables resulted in significant energy savings, up to 70%, due to the proposed the thermal envelope upgrade
- The variations in the façade design, given similar thermal properties, have a marginal effect on the energy demand
- The construction of a winter garden is possible without an increase in the rent
- Energy generation through the use of PV and solar collectors is cost-effective, as it has a considerable positive effect on the energy use and the energy cost, without increasing the rental price.

It is important to note that the savings on energy costs are greater than the capital burden of the energy-saving measures discussed in the current study. As a result, the total living cost to decrease in all cases. This conclusion is important to support the implementation of energy efficient measures; if the whole exploitation period is considered, the refurbishment is financially feasible, without burdening the household expenditure.

One of the main objectives of the study was not only to identify the effect the different parameters would have but also to inform the current practice in the context of energy efficiency upgrades of multi-residential buildings. To this end, the variations studied were selected based on commonly realized upgrades and focus groups with architects and users, and not in the interest of highlighting the effect on energy and cost. Thus, even if some of the variations result in non- significant differences for the KPI's, they are still valuable result to support decision making and provide options in the refurbishment strategy design.

The method presented in this paper was based on the energy efficient refurbishment measures and the specific KPI's. Other measures that may not be as cost-effective but do have additional environmental or living quality benefits, which can also increase the property value. These measures cannot be identified with the research method followed, which focused on energy efficiency. The conclusions on energy efficiency upgrades need to be considered both by the designers and other stakeholders, most importantly the occupants who will benefit of the reduced energy use, but also will need to pay the possible increase in the rent.

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