A Technical and Energy Performance Approach for the Construction and Operation of the Zero-energy Renovation of a Residential Building in the Netherlands

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and practice; creation of new climate-adapted design parameters; expansion of the design repertoire and reflection on the possibilities of applying different bioclimatic strategies in architectural design; understanding of the methods used to define bioclimatic in each climate. This activity can also be performed using different types of different buildings (school, commercial, institutional); in another architectural style; and in different cities. It is suggested that the activity be carried out in the Thermal Comfort and Architectural Design discipline. This method of analyzing case studies makes it possible to sensitize the student and designer to the dissemination of good design practices in thermal comfort, health and energy efficiency, as well as the application of bioclimatic in future projects.

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A technical and energy performance approach for the construction and operation of a zero-energy renovation of a residential building in the Netherlands

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ABSTRACT: Accounting for almost 40% of energy consumption in the European Union, the role of the existing building stock is instrumental in the energy transition and the goals for carbon neutrality of the built environment. An effective renovation plan must significantly improve the current energy performance towards a nearly zero-energy level. Nevertheless, renovation that addresses the energy performance of buildings is at a rate as low as 1%, with deep renovation being at 0.2%. The low rate can be attributed to the higher complexity and costs incurred due to the high number of retrofitted components and the integration of renewable energy sources, the many actors involved and barriers such as split incentives and availability of funds.
This paper discusses the process that led to a zero-energy renovation of a previously outdated post-war, mid-rise, tenement apartment building. This process included design, execution of the technical measures, energy contracting and monitoring. The aspects considered during this project focus on the technical solution, including the building envelope and services upgrade and the performance guarantee that made the project a successful business case. The results showed that the renovated building is zero-energy and the energy production overcompensate for the energy demand. The steps that were taken ensured a renovation concept development towards upscalability. Lessons learned during this project have enabled the involved stakeholder to extend the renovation concept to address various buildings types and performance goals.
KEYWORDS: zero-energy renovation, energy performance guarantee, building refurbishment

1. Introduction

Accounting for almost 40% of energy consumption in the European Union (Tsemekidi Tzeiranaki et al., 2020), the role of the existing building stock is instrumental in the energy transition and the goals for carbon neutrality of the built environment. To tackle this potential, the rate and depth of renovation need to increase (Artola et al., 2016). Today the annual renovation rate of the building stock varies from 0.4 to 1.2% in the Member States (European Commission, 2020). This rate will need at least to double to reach the EU's energy efficiency and climate objectives (European Commission, 2019). The low rate can be attributed to the higher complexity and costs incurred due to the high number of retrofitted components and the integration of renewable energy sources, as well as the many actors involved (Bystedt et al., 2016; D'Oca et al., 2018). Furthermore, the split incentive between the tenants who benefit from the energy savings and the landlords who do not have sufficient incentive to invest in improving the property (Atanasiu et al., 2014) is identified as one of the most long-lasting barriers.

An effective renovation plan must significantly improve the current energy performance towards a nearly zero-energy level. Zero-energy does not necessarily imply zero-carbon, as the carbon emissions also depend on the energy supply system on regional and national level (Galvin, 2022). A Zero Energy Building (ZEB) is a building with greatly reduced energy needs and/or carbon emissions, achieved through efficiency gains and renewable energy. ZEB can be referred to as a Zero Energy Building and Zero Emission Building. The first considers the energy consumed by a building in its day-to-day operation, and the second is the carbon emissions released into the environment as a result of its operation (D'Agostino & Mazzarella, 2019).

In both cases, to reduce the energy demand, zero-energy renovation needs to upgrade several building components to reach an improved performance. The integration of many components increases the complexity and the cost of those renovations. Energy performance contracts (EPCs) offer the option of performance guarantees which can reduce risks associated with complex projects. Given that they enable funding of energy renovations from energy cost savings, they successfully tackle upfront cost barriers for consumers (Bertoldi et al., 2021).

This paper discusses the process that led to a zero-energy renovation of a previously outdated post-war, mid-rise, tenement apartment building. The aspects considered during this project focus on the technical solution, including the building envelope and services upgrade, and the performance guarantee model that made the project a successful business case.

2. Method

2.1. Renovation design and execution

The objective of the project was to demonstrate the feasibility of a zero-energy renovation. The standard needed to achieve in this project was “Nul op de meter (Zero on the meter)”, which means that the yearly average energy consumption is zero (RVO, 2016), including heating, domestic hot water (DHW) and appliances. Achieving zero-on-the-meter performance was also essential for the business case, as makes it possible to apply the “energy performance subsidy (EPV)” regulation (RVO, 2017), that allows for a fixed amount per m2, per month to be compensated to the building owner for the improved performance. The subsidy is not part of a rent increase.

The first concern is to include all the necessary measures to achieve the zero-energy goal and allow for the performance guarantee. Next to the selected technical upgrade interventions, the construction process is very important. It constitutes the proof that the renovation is feasible and applicable while the occupants are living in their dwellings. The planning needed to follow some basic principles in order for the construction process to be as little disturbing for the occupants as possible and of course, safe and efficient. Those attention points highlighted process issues to consider for the planning, such as that the residents cannot stay with no heating or warm water and that a maximum of five days of construction work inside each apartment is allowed.

Taking into account the above mentioned and the time needed for the manufacturing, transfer, and installation of the components, the construction team planned and successfully executed a detailed timeline for the renovation process for all 12 dwellings over 15 weeks. The renovation was completed in February 2018.

2.2. Energy calculations and Energy contract

Given the zero-energy objective, the energy demand and energy generation were central in the renovation's decision-making. Moreover, estimating the energy use was essential to determine the conditions of the energy contract.

The calculation was made through the tool Uniec[2] (Earth Energie Advies, 2017), which is an accredited software for calculating the Energy Performance Coefficient (EPC) in the Netherlands, defined by the NEN7120 building degree (NEN, 2017). The calculation method is a static calculation on the theoretical energy demand based on standardised inputs. The output of energy generated is calculated according to the Photovoltaic panels’ specifications. This software was considered appropriate for the project, as it facilitated the communication between the design team and the building owner and occupants. Moreover, the calculation of the EPC and the benchmark value of 0,2 is the precondition to apply for the EPV.

2.3. Monitoring

A wide array of techniques is available for monitoring. Post-occupancy evaluation of a building can be done through surveys on comfort and perception of temperature and climate; qualitative methods such as diaries can be used to evaluate the usability of systems and building; and objective measurements can be taken regarding indoor environment in relation to the weather (Guerra-Santin & Tweed, 2015).

For the current research, a combination of existing methods was chosen. Temperature, CO_2 levels, and humidity can be measured relatively straightforwardly and give a good indication of thermal comfort compared to norms and measured over more extended periods of time. Furthermore, a fine-grained dataset of indoor climate measurements provides rich data for analysis which can then be linked to clear instances of occupants’ practices or difficulties in use (Guerra-Santin et al., 2017). This data also allows for a comparison with a simulation of the performance of the occupied building [source]. Finally, if occupants are well informed of the research, the use of sensors in the home does not have to lead to too much disruption.

In addition to the indoor climate measurements, interviews and walkthroughs were organised in occupant visits, where the data could be coupled with the preferences and practices of the residents and problematic issues in the buildings. This offers an occupant perspective and more in-depth information that will help formulate learnings for future projects.

Each of the ten dwellings was fitted with three monitoring devices [**Figure 1**]. These sensor boxes record and transmit the measurements for indoor temperature, levels of CO_2, and humidity in 3-minute intervals. One of the three sensor boxes was placed in the living room, one in the kitchen, and one in the front room. Bedrooms where not monitored because the ethical approval for the study had to be obtained within a short time frame.

Figure 1: The monitoring boxes installed in the dwellings, developed by industrial partner OfficeVitae.

Next to this, the residents received a booklet that helped them reflect on their own thermal and climate comfort and practices pre-and post-renovation.

The present paper reports indicative results of a preliminary post-occupancy evaluation of the period until 2019.

3. Strategy to zero-energy renovation

3.1. Renovation solution

The main objective of the building envelope upgrade is to reduce the heat losses through the building elements. The high thermal resistance of the envelope, indicated by the values in Table 1, is essential to the heating demand. Combined with the Heat Recovery Ventilation, it allows for low-temperature heating sources (Wang, Ploskić, Song, & Holmberg, 2016).

The renovation resulted in excellent insulation and airtightness, featuring external insulation on the walls, new window frames with triple gazing , prefabricated insulated roof panels, photovoltaic (PV) panels.

As suggested by the national energy goals, the building is disconnected from the gas, which complies with the current energy policy. The heating and DHW is provided by the ground-source heat pump of COP6. The heat pump, water tank and heat-recovery ventilation unit are placed in prefabricated, insulated boxes located outside the apartments on a new, enlarged balcony. The building consortium partners provided the building owner with maintenance and energy performance guarantee.

3.1. Energy use and generation,

During the design phase, the project team calculated the energy demand as part of the building permit process and determined the energy performance guarantee. The energy calculations show a net energy surplus on an annual basis for standardised occupancy.

Table 1: *Overview of technical options of the Demonstrator and Scaler projects. The explanation column includes the reasons for deciding for different measures in the scaler project*

Wall	Rigid expanded polystyrene Plaster finishing U=0,16 W/Km2,	
Windows	u-PVC frames Triple glazed panes Uw=1 W/Km2, g=0,8	
Roof	Sandwich Insulation panels U=0,14 W/Km2	
Ground floor	Expanded polystyrene in granulated form blown crawling space U=0,28 W/Km2	
Balcony	Old balcony removed and replaced with new steel structure, on new foundations	
Entrance	New closed entrance	
Ventilation	Mechanical ventilation with heat recovery, up to 95%,	
Heating	Ground-to-water heat-pump COP 6.00 (one every 3 apartments)	
DHW	Ground-to-water heat-pump COP 3.00 (one every 3 apartments, one water buffer per apartment).	

For reference, earlier studies (Guerra-Santin et al., 2018) suggested that this type of dwellings are expected to consume on average approximately 2300kWh/yr for heating and DHW, and 2800 kWh/yr for appliances, with the possibility to reduce to 1600 kWh/yr, if they switch to high efficiency appliances. **Table 2** presents details on the energy use and production per dwelling. The total projected energy use of 3106 kWh/yr constitutes a 60% reduction from the 5100 kWh/yr reference energy use.

To reach the zero-energy standard, energy production on-site is needed. To this end, photovoltaic panels with a capacity of 300 Wp are installed, both on the south and the north sides of the roof. Given the roof area, each apartment receives 8 photovoltaic panels oriented to the South, resulting in a yield of 2,304 kWh to cover their household consumption of 1,800 kWh. One dwelling gets 2 panels on the South and 10 on the North. The remaining 80 panels on the north produce additional energy to ensure that the zero-energy objective is met.

Due to the excess of PV panels compared to the calculated energy demand, there will be a surplus of energy on building level. This energy can be saved for future years, when the PV output energy is reduced due to degeneration of the panels or the occurrence of colder or less sunny years. The risk of missing to compensate the energy demand is thus reduced.

Table 2: *Calculation of the energy use (with no cooling) and the energy generation with PV with 300Wp, per dwelling, per year.*

Area apartment (m2)	59
Energy use building services (kWh)	353
Energy useDHW (kWh)	487
Energy use - Building related (kWh)	840
Energy use - user related (kWh)	1800
15% reserve (kWh)	466
Total energy demand (kWh)	**3106**
Energy generated from PV - 8panels south (kWh)	2304
Energy generated from PV - collective panels north (kWh)	1230
Total energy generation (kWh)	**3534**

Those calculations allowed for a 25-year zero-energy performance contract to be agreed upon between the building services provider and the building owner. According to the agreement, the building services provider guarantees the maintenance of the systems and the energy demand for a fixed amount per dwelling.

Furthermore, to overcome the split-incentives barrier, the housing association signed a contract with each occupant for their energy use. The energy budget for space heating and DHW, guaranteed by the building services, is 966 kWh per year, per dwelling, which is 15% over the calculated demand (Table 2)

4. Post-occupancy evaluation

4.1. Energy use

After the building renovation completion, the performance monitoring continued, as part of the energy performance contract, between the building owner and the building services provider. **Table 3** provides an overview of the energy used for space heating and DHW and energy generation. Because there is one heat pump for every three, vertically-stacked apartments, the energy consumption metered by the heat pump is divided equally by 3 in the table.

The first observation is that the energy use in 3 out of 4 cases is higher than the 840 kWh per apartment predicted (**Table 2**). Since this heat pump consumption includes both space heating and DHW, we cannot separate if it is building- or user-related. Nevertheless, the PV generation is also higher than predicted. As a result, and taking into account the contracted household electricity of 1800kWh, there is an energy surplus

Table 3: *Energy use and energy generation for the period 1-1-2019 until 31-12-2019, in kWh/year*

	Energy use – Space heating + DHW	**Energy generated from PV**	**Energy use - user related energy contract**	**Energy surplus**
1-G	852	3785	1800	**1133**
1-M	852	3807	1800	**1155**
1-T	852	3836	1800	**1184**
2-G	1427	3821	1800	**594**
2-M	1427	3856	1800	**629**
2-T	1427	3825	1800	**598**
3-G	1149	3127	1800	178
3-M	1149	3297	1800	348
3-T	1149	3827	1800	878
4-G	1511	3823	1800	**512**
4-M	1511	3790	1800	**479**
4-T	1511	3593	1800	**282**

4.2. User related energy for appliances

The user-related energy usage slightly exceeded their projected use of 1800kWh, but the solar panels for the heat pump consumption produced a surplus of energy. Energy usage data is unavailable from all houses because electricity is contracted separately with the energy company. An example of one household provided below, based on the household's energy bills for their personal energy use (appliances). It shows that energy yield comes close to energy use for the household's individual energy use, after renovation.

Table 4: the energy use and energy generation (in kWh) for June 2016- June 2019 for one household's personal appliances. The yield differs from Table 3 because only the PV for personal energy use are included.

	Jun2016 Jun2017	Jun2017 Jun2018	Jun2018 Jun2019
Energy use, off-peak	1509	1451	1262
Energy use, peak	1547	1178	785
Total energy use	3056	2629	2047
Energy yield, off-peak	-	457	480
Energy yield, peak	-	1093	1193
Total yield	-	1550	1673
Net energy use	**3056**	**1079**	**374**

The table shows the difference in that household's energy use before and after the renovation. The renovation took place during the winter of 2018. The household's energy use post-renovation still exceeds the yield by 374 kWh. However, the table does not yet reflect the full yield that can be expected for the resident's next energy use period. As mentioned above, this surpassed 1800 kWh in the first eight months of 2019. Additionally, the yield of the other set of solar panels, those for the building services, was higher than needed, adding to the surplus to be expected.

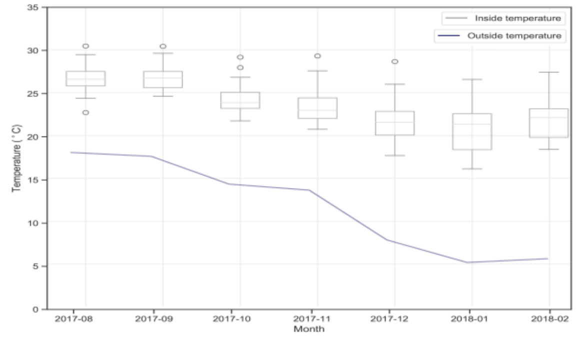
The resident's lower energy use over these three years (from 3056 kWh to 2629 kWh to 2047 kWh) can be explained by the refurbishment: insulation, switch to led lighting (residents received a gift set), efficient installations and switch to induction cooking.

4.3. Comfort, preferences and practices

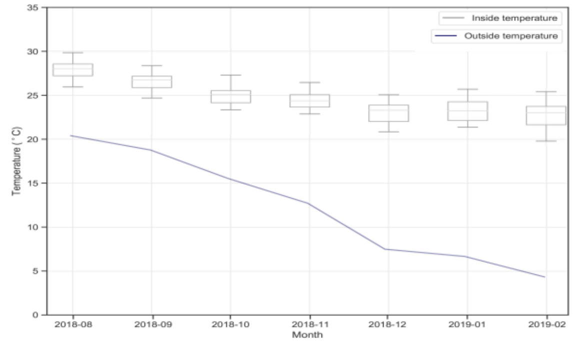
Both the CO_2 levels and the temperature in the households have stabilised since the renovation of the building. Indoor air humidity has also decreased and stabilised between 30 to 60 %, reducing fungus and dampness in the ground floor apartments, which was an issue before the renovation. However, in two households, CO_2 levels are measured that are too high for continued periods. Some of these issues could be resolved by changing the ventilation setting. The CO_2 levels were significantly lowered after the residents were advised to change the setting.

The temperature of the households has stabilised significantly since the renovation. The data shows that the temperature rarely drops below 18oC in winter (**Figure 2**). However, the indoor temperatures in the top floor apartments reached more than 26oC above 25% of the time, including nights during June, July and August of 2019, with a maximum of 31oC. The summers of 2018 and 2019 were hot compared to average weather data. This led to an average temperature in households on all levels of 26oC during 21-25 of July 2019, with only one-degree cooler at night. Homes sometimes were 28 degrees warm at night. Short-term temperature peaks over 26oC also happened during other times of the year, mainly in the early evenings, after cooking and sun exposure in south-facing living rooms.

Many of the ten households monitored had bought additional heating devices for the winter. Although the temperatures were now much more stable, with drafts removed and all rooms heated evenly, some residents felt they would like a bedroom to be cooler or warmer than the rest of the home. Some felt that even a temperature of 22oC was too cool, while others would have preferred a temperature of around 20 degrees. A stable temperature is valued by all residents, although at different levels. In addition, they would also like to be able to change the temperature to their preferred level.



Before renovation



After renovation

Figure 2: Line and box plot: The period of July to January is taken for 2017-2018 (before renovation) and 2018-2019 (after renovation). A boxplot is made for each month to compare the relationship between indoor and outdoor temperature over time (graph by Heleen Oude Nijhuis and Rene van Egmond).

Overall, the residents reported high satisfaction with the renovated homes. The key points of satisfaction were the absence of fungus, drought and humidity in the homes post-renovation. The increased temperature stability was an additional point of satisfaction, as were lower peak indoor temperatures in summer than in pre-renovation. The aesthetic quality of the exterior of the building was also an essential point of satisfaction for the residents. The residents reported lower satisfaction and dissatisfaction with their limited ability to set the temperature at the desired level. The residents also reported low satisfaction with the user interfaces of the building services, such as the ventilation interface and the activities they needed to perform for maintenance on the ventilation filters. These aspects can potentially affect building performance in the long term.

5. CONCLUSION

The paper presented a zero-energy renovation concept applied to a multi-residential building of 12 apartments in the Netherlands. The concept addressed the technical aspects, including the building envelope and services upgrade and energy generation application through PV panels. Furthermore, it offered an energy performance guarantee to the building owner, who was able to provide an energy performance contract to the residents.

The combination of measures to reduce the energy demand and maximise the energy generation achieved and went beyond the zero-energy target. Even though some households exceeded the predicted energy demand of 840 kWh/yr, the PV yield exceeded the calculated production, resulting in an energy surplus. In this sense, the reduction in energy use was 100%.

Moreover, the energy performance contract resulted in a viable business case without increasing the rent after the renovation. This is a significant achievement, given that the increased costs for the building owner are one of the main barriers to implementing zero-energy renovation concepts. Energy performance contracts proved an effective way to implement a complex zero-energy renovation strategy and can be a tool for upscaling renovations.

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