Effect of design assumptions on the performance evaluation of zero energy housing

O Guerra-Santin[1,3], L Xu[1,2], S Boess[2], E van Beek[2]

[1] Department Built Environment, Eindhoven University of Technology, Den Dolech 3, 5612 AZ Eindhoven, the Netherlands
[2] Faculty of Industrial Design Engineering, Delft University of Technology, Landbergstraat 15, 2628 CE Delft, the Netherlands

[3] o.guerra.santin@tue.nl

Abstract. Renovation projects in social housing tend to focus on diminishing the costs of the renovation. An affordable solution is sought for an average household, thus assumptions are made about the residents' behaviour when calculating the energy performance of the dwellings. However, households have different needs and preferences, and therefore the actual use of the building can affect the achievement of the zero energy goals. In the Netherlands, until 2020, the calculation of the energy performance coefficient (EPC) was necessary to obtain building permission. The EPC was calculated based on standardised occupancy, and took into account the characteristics of the building envelope and installations. Furthermore, the EPV (energieprestatievergoeding, energy performance compensation in English) is an instrument used by housing associations and landlords to recover part of their investments in renovating social housing into (nearly) zero energy homes through a regulated increase in the rent, while protecting the residents from increase on their costs of living. In this research, we used a monitoring case study in the Netherlands to investigate the effect of assumptions made during design regarding occupants' behaviour, preferences, needs and lifestyle on achieving energy neutrality goals. The following questions are answered: What assumptions where made during the design of the building, and how do they differ from actual behaviour?, and what are the consequences of the behaviour for the performance of the building and for the EPV? The objective of this research is to determine the importance of design assumptions in the design and evaluation of zero energy buildings.

1. Introduction

Renovation projects in social housing tend to focus on diminishing the costs of the renovation. An affordable solution is sought for an average household, thus assumptions are made about the residents' behaviour when calculating the energy performance of the dwellings [1]. However, households have different needs and preferences, and therefore the actual use of the building can affect the achievement of the zero energy goals [2]. In the Netherlands, until 2020, the calculation of the energy performance coefficient (EPC) was necessary to obtain building permission. The EPC was calculated based on standardised occupancy, and took into account the characteristics of the building envelope and installations. Furthermore, the EPV (energieprestatievergoeding, energy performance compensation in English) [3] is a Dutch instrument used by housing associations and landlords to recover part of their investments in renovating social housing into zero energy homes through a regulated increase in the rent, while protecting the residents from increase on their costs of living. Therefore, housing with EPV require building monitoring.

Although, efforts to renovate the building stock are evident, and monitoring the performance of buildings is more common, there is a prevalent lack of reporting on the findings of real life projects. This makes it difficult to learn from current practices that could benefit the energy transition.

In this paper, we investigate the effect of assumptions made during design regarding occupants' behaviour on achieving energy neutrality goals, as well as the consequences for building performance evaluation. Furthermore, the goal of this paper is to draw conclusions from a monitoring campaign in 4 renovated flats, in terms of the common pitfalls of monitoring and evaluating real life projects.

The following questions are addressed:

- What assumptions are made during the design of the building, and how do they differ from actual behaviour? What is the baseline performance for the evaluation of the project?
- What are the consequences of the behaviour for the performance of the building and for the EPV?
- How building monitoring can be improved in current renovation projects to properly evaluate building performance?

This paper focuses on the actual performance of zero energy housing in the Netherlands, considering both energy consumption and indoor environmental quality. This paper highlights the importance of design assumptions in the performance of buildings, and the role of the occupants behaviour and monitoring in successful projects.

2. State of the art

A review [4] on recently built energy neutral dwellings was carried out to determine the state of the art in their performance. The review showed that all reported projects claim to have achieved energy neutrality. However, it was also found that higher expected energy consumption for one aspect (e.g. dhw, heating, domestic electricity), compensate for lower than expected energy consumption in other aspect. For example in some projects, lower energy consumption for dhw or domestic uses (cooking, appliances, etc.) compensated for higher energy use for heating.

From a statistical perspective van den Brom [5] found that most buildings do not perform as expected, therefore the trend seen in these reviewed (public) project reports differs from those seen in the whole building stock. The reasons might be because only successful cases are reported, or because building monitoring contributes to a better performance.

Furthermore, in the review it was found a lack of in-depth investigation on the causes for deviations on energy performance. These are usually attributed to functioning of the systems or occupants' behaviour, but it is seldom checked through further monitoring.

3. Data and methods

3.1. Case study

The case study consists of a zero-on-the-meter social housing renovated project in the Netherlands. The building studied is a porch flat from the years 1950s renovated in the period 2017-2018. There are 12 flats in the building, from which 4 were selected to be monitored in detail. Each flat has a living area of around 50 m2, and consist of a living room, kitchen, two bedrooms, toilet, and separate shower with access from the kitchen.

The project consisted of a façade renovation with insulation and pre-fabricated elements, new double glazing windows, renovated balconies (separated from the main body of the building to decrease thermal bridges), heat recovery ventilation system, all-electric low temperature ground source heat pump system (shared among three flats) for heating, cooling and domestic hot water with a buffer tank (per flat), and solar panels. Showers, toilets, and kitchens were also renovated.

The previous high temperature heating system with radiators was upgraded to a low temperature system with convectors. The convectors have a 'boost' function providing warm/cool air at a higher speed, for when the residents want to heat or cool the spaces faster. The old thermostat was replaced with a manual thermostat that can be adjusted from 18 to 24°C. The heat recovery ventilation system includes outlets in kitchen, shower and toilet and inlets in the living room and bedrooms. The control panel allows the resident to select one in four modes: low setting, normal setting, high setting and boost setting with a timer of 10, 20, or 30 minutes.

90 photovoltaic panels were installed for energy generation, producing 41,732 kWh per year. Half were connected to the heating system and domestic hot water production system, while the other half were connected to supply the apartments for domestic electricity. Each apartment was connected to 8 PV panels. The complex was provided with 4 meters, one per block of 3 apartments, for the measurement of energy used for heating, dhw and auxiliary energy. The billing for these 4 meters are addressed to the housing association. Each apartment is provided with a meter to measure their domestic electricity consumption and electricity production of the PV panels allocated to the household. The bill for these meters is sent to the residents of the building.

3.2. Monitoring campaign

Four apartments were monitored for two weeks on different dates during the winter and early spring of 2020. Energy data was obtained from the housing association regarding the use of electricity for domestic hot water, heating and auxiliar, as well as the production of electricity by the household-bound solar panels. Data on the building-bound solar panels was not provided.

The housing association also provided the EPC and EPV calculations made before the renovation of the building. From these documents, we determined the design assumptions regarding occupants' behaviour that were considered in the design phase. The housing association uses these documents to evaluate the performance of the building.

3.3. Methodology

In the study, we follow a methodology previously developed and presented in [6] to determine the expected energy performance of the building to compare with the actual performance. This previous research has indicated that design assumptions regarding occupants' behaviour can affect the way in which buildings are evaluated. Design assumptions were investigated through a design review based on talks with the designers and revision of design documents. The expected energy consumption and occupant behaviour is determined and compared with actual energy consumption and occupant behaviour (Figure 1). Actual energy consumption was provided by the housing association (bills and metering data), while actual behaviour was determined based on interviews with the occupants (walkthrough), questionnaires, diaries, and monitored building parameters (Temp, RH, CO_2 level) according to the methodology developed and explained in [7].

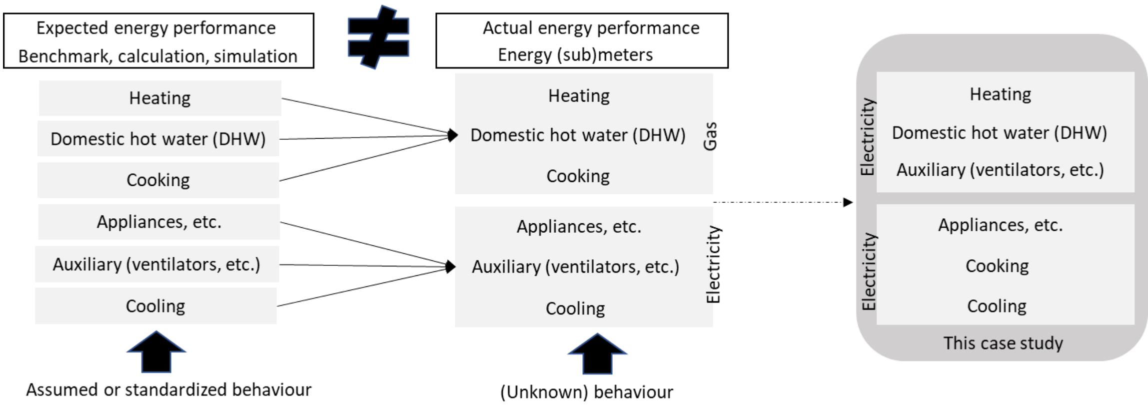

Figure 1 Main challenges in the evaluation of buildings

Figure 1 shows two main challenges in the evaluation of buildings: 1) the metering strategy (combined data for several energy final uses – heating, cooking, dhw, etc.), and 2) the "noise" produced by assumed or standardised behaviour for the expected energy consumption, and by the unknown occupants' behaviour in the actual energy consumption. Figure 1 also shows the specific metering situation in the case study.

4. Results

4.1. Design/calculation assumptions

The EPC (old Dutch performance base building regulations) is a dimensionless figure indicating the performance of the building, accounting for the dimensions and geometry of the building. The EPC (energy performance coefficient) expresses the energy efficiency of a building on the basis of the energy demand for heating, hot water, lighting, ventilation, humidification, and cooling. The EPC is determined by dividing the calculated energy requirement of a building by a standardised energy performance, which is based on the heat-transfer surface and the total heated area of the dwelling. The EPC applies a correction for building size to avoid penalising larger dwellings or dwellings with larger heat loss surfaces (e.g. corner houses or detached houses). According to these documents, the expected performance of the case study building can be found in Table 1.

Table 1 Expected energy demand according to EPV calculation report

Block	Total demand	Domestic electricity bundle	Heating, dhw, aux	Heating	dhw + aux	(dhw)	(aux)
B1	7,740	5,400	2,340	807	1,533	816	717
B2	7,410	5,400	2,010	533	1,477	816	661
B3	7,410	5,400	2,010	533	1,477	816	661
B4	7,740	5,400	2,340	808	1,532	816	716
Total	30,300	21,600	8,700	2,681	6,019	3,264	2,755

4.2. Actual occupants' behaviour

The occupants behaviour of the four monitored apartments is reported in the Table 2. This information was gathered through interviews with the residents and data from the short term monitoring campaign. The table also shows the expected behaviour according to the installers, as well as the average behaviour considered in the EPC calculations.

Table 2 Expected and actual occupants' behaviour

	Heating	Windows and doors	Mechanical ventilation	Showering	Satisfaction
Behaviour expected by installers	20ºC all the time. Use of boosters in convectors for extra heat.	No need to open windows in the winter. Internal doors open day and night.	Lowest stand (1) when not at home. Medium stand (2) when home, highest stand (3) or Boost when cooking or showering.	N/a	N/a
Average behaviour according to calculations	Living room and bedroom 20ºC; bathroom 22ºC;	No need to open windows in the winter.	25 m^3/hr	0.9 showers per day per flat.	N/a

Table 2 Expected and actual occupants' behaviour (continuation)

	Heating	Windows and doors	Mechanical ventilation	Showering	Satisfaction
HH1 behaviour	20-21ºC. No interaction with convectors. Adjustment of clothing.	Window open in winter in bedroom. Bedroom door closed. Courtyard door open in summer.	Lowest stand (1) Boost or higher option if cooking or showering.	1 person household.	Dissatisfied with system control and speed: not able to heat or cool rooms if needed.
HH2 behaviour	Thermostat set up to 18-19ºC. No use of convectors.	Ventilating via windows and balcony door. Opening the door to the balcony at night.	Always on setting 2 (standard) and use of boost during showers.	1 person household.	Satisfied with temperature. Air too dry. Not satisfied with systems control.
HH3 behaviour	Thermostat set up to 24ºC. No use of convectors. Use of extra electrical heating.	Cross ventilation while cleaning once per week.	Always on setting 1 and use of boost during showers, cooking and smoking.	4 persons household.	Residents feel too cold all the time. Dwelling is too small for residents.
HH4 behaviour	Thermostat set up to 20-22ºC for a short time. Rest of the time off (below 18ºC). Use of fan function in convectors. Makes use of clothing to feel warmer.	Ventilating via windows and balcony door during the day. Windows closed at night.	Always on setting 1 and use of boost during showers.	1 person household.	Satisfied with temperature and ventilation. Not issues with systems control.

The residents reported very different behaviours to those expected by the installers, to those used in the calculations, and also among them. In Table 2, the cells in grey indicate those behaviours closer to the expectations. There were different reasons for the residents to use the systems different than instructed. The residents reported to keep the ventilation system on a lower setting than recommended due to the noise the system produces (3 out of 4 households). The thermostat setting and the natural ventilation behaviour depended on the residents' preferences for thermal comfort and fresh air. Household 2 and 4 reported to keep windows open (even in winter) because they like to feel the fresh air and have a preference for cooler environments, while resident of household 1 opens the window in the bedroom some nights because she prefers to sleep in cooler environments. On the contrary, residents of household 3 reported to not open windows during the winter because they felt always too cold in the apartment.

4.3. Consequences for performance – indoor comfort

Analysis of the indoor environmental environment parameters in the four apartments showed the effect of the behaviour on the indoor performance. CO2 levels where high in households 1, 2 and 4, which kept the ventilation system on level 1, and closed windows all night. In case of household 1, windows would be open sometimes at night to decrease the temperature of the room, also improving the indoor air quality.

Temperature preferences varies among the 4 households. Household 2 and 4 like prefer very fresh and cool indoor environment, while household 1 prefers an average temperature of 20 to 22 degrees in the living room, but a much colder bedroom to sleep. The residents of household 4 indicated a preference for warmer environments since a temperature of 22ºC was still considered cold. They reported to keep the thermostat on 24ºC throughout the year, but the system can only provide up to 22ºC. Thus, the residents opted for using extra electrical heaters a few times per day.

The monitored data showed that, in terms of accepted standards for thermal comfort, the building is able to maintain very good and steady indoor condition for the residents, if windows are kept closed, the ventilation system in setting 2, and the heating on 20-22 degrees. Furthermore, according to the residents, they do not suffer much from overheating in the summer. However, residents of households 1 and 2 were unsatisfied with the temperature in the bedrooms, which was too high for them to sleep. These two apartments showed to have higher temperatures in some rooms in the winter/spring. Furthermore, household 3 complained of their home being too cold for them. This household has a foreign background.

4.4. Consequences for performance – zero energy performance

The following table shows the energy consumption for heating, dhw and ventilation for each of the 4 building blocks since individual meters per flat were not installed. The meters only show the performance per block of three apartments, thus, it is not possible for the housing association to know which households have a higher consumption. Also, having the heating, dhw and ventilation combined in one meter, hinders the energy performance evaluation. Furthermore, the meters for the energy consumption only show the data after the own use from the PV panels, thus, the actual energy consumption is higher than shown in the energy bill. Based on the energy production of the PV panels for domestic electricity (thus, not the ones used for own use for heating, dhw and auxiliary), we estimated the actual energy consumption of the building.

Table 3 Measured energy for heating, dhw and auxiliary, and estimated heating and dhw plus auxiliary excluding own use (eigen gebruik) from the PV panels

Block	Heating, dhw, aux	Heating	dhw + aux
B1	2,420	1,096	1,319
B2	5,736	2,348	3,370
B3	3,287	702	2,524
B4	4,794	1,965	3,082
Total	16,238*	6,110	10,295

Based on the design assumptions, and the actual data from the monitored households, we can see that the energy demand might be higher because 1) household size are not always conformed of one person, as assumed for the dhw calculation; and 2) natural ventilation habits of the residents might be increasing the energy demand for heating, although the ventilation system level kept in level 1 might be decreasing energy consumption for ventilation.

From the data collected, it seemed that the system is not able to provide a higher indoor temperature than 22ºC, and thus some households use extra sources of heat. These sources however, are connected to the domestic electricity consumption, and so, these are unknown by the housing association, and might be affecting the domestic electricity budget of these households. These households are paying

EPV and might be paying a higher electricity bill (outside of their bundle) due to the use of electrical heaters.

Table 4 Estimated total energy consumption for heating, dhw and auxiliary, including own use (eigen gebruik) from PV panels ([E]=estimated; [B]=billed; [C]=calculated)

Consumption			Production			
Energy use [B]	Own use [E]	Total energy incl. own use [E]	Expected [C]	Actual production [E]	Returned [B]	
16,822*	6,292	23,114	14,400	17,833	11,541	PV building
			25,920	32,100	N/a	PV flats

(*) In table 3 and 4 Energy use do not completely match do to differences between monitoring and billing period.

5. Discussion and conclusions

The data collected showed that in terms of thermal comfort, the building is able to provide a good indoor environment, according to current standards. The ventilation system seems also to be able to provide a good air quality when it is used correctly. However, given the preferences of the occupants for fresh air and indoor temperature, as well as the noise produced by the ventilation system, the residents are not fully satisfied with the indoor environment and therefore react to restore their comfort by opening windows, turning the ventilation system to the lowest setting, and using extra heating appliances, which have consequences both for the indoor environmental quality, and for the building energy performance.

Even though the results indicate that the building performs well, from the point of view of the housing association, there is a problem with the performance of the building since they still have to pay an energy bill. Given the combined metering for three flats, the housing association cannot know which household is using more energy, thus they cannot bill the individual households for the extra use of energy, or compensate those that use less energy.

In other projects, higher energy consumption than calculated for dhw or heating is compensated either by some households using less energy than others, or by a lower use of domestic electricity. In this building, the problem is caused by the split bills between the housing association and the tenants. In theory, according to the EPV contracts, residents can heat their houses to a higher degree (or open windows) but this means that they have to pay more for the extra energy they consume. In most projects, neutrality is reached due to the balance between building related and user related energy consumption [4].

When calculating the energy performance of the building during the design phase, assumptions are made to calculate the systems, however these assumptions can be taken too literally with respect to performance. Since the assumptions for design are based on average households, they cannot truly reflect the actual behaviours of the occupants. In this case study, the housing association expected the energy consumption to be close to the calculated values, but this was always unachievable. Some regulations, for example the NTA 8800:2022 NEN already show a disclaimer on the actual purpose of the software/calculations, which is to provide a benchmark to make buildings comparable. This models or calculations use, on purpose, an average behaviour not because they assure it is recommendable or accurate, but because it is the way to control for it. The methods are not intended to predict energy consumption, but are only meant to be used as an aid in the design process. This case study showed that design assumptions differ too much from actual behaviour.

In average, the energy consumption of the case study might fall into energy neutrality, the problem arises from the fact that the housing association still have to pay for energy every year, and the lack of accurate monitoring data to carry out a good assessment. The system was designed in a way that the metering and billing of energy for heating and dhw were separated from the energy for domestic electricity. The surplus of energy for domestic electricity benefits the residents, but not to the housing association, while the occupants' behaviour affects the use of heating and dhw, which increases the energy consumption bill that has to be paid by the housing association. Furthermore, for heating, dhw and auxiliary energy, the metering was installed per blocks of 3 households, thus knowing individual energy consumption impossible. This metering arrangement hinders the energy performance evaluation because it is difficult to explain the excess on energy consumption. Furthermore, the split metering/billing of the building also makes 'invisible' the increase on energy consumption cause by extra heating devices to the housing association since it is only reflected on the energy bill of the residents. This further hinders the energy neutrality assessment of the building.

This paper highlights the need for user friendly energy performance calculations tools and frameworks that can more accurately predict energy consumption that can be used by practitioners in real life projects, as well as the need for better consideration on monitoring needs during the use phase of the buildings.

Based on the findings of this research, the following recommendations for monitoring and evaluation are:

- Use a more suitable simulation program or find a reliable benchmark for comparison.
- Meters and submeters installations per dwelling, if possible per final use (heating, dhw, auxiliary, domestic electricity).
- Indoor measurements of at least: indoor temperature in the main bedroom and thermostat room (usually the living room), CO2 levels (at least in the bedrooms).
- Thermostatic setting information (data or via residents)
- Natural ventilation behaviour, and preferences for fresh air and temperature in bedrooms.
- Energy neutrality will probably be achieved on building level.
- Consider existing residents in the evaluation: if there are many older residents or families, it is likely that they will require more energy for heating or domestic electricity respectively.

6. Acknowledgments

This project is executed with the support of the MMIP 3 & 4 grant from the Netherlands Ministry of Economic Affairs & Climate Policy as well as the Ministry of the Interior and Kingdom Relations.

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