Towards a future sustainable housing stock
Assessment of the energy performance of dwellings of non-profit housing associations
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Summary

Climate change asks for urgent action. For decades humankind is aware of the impact of humanity on our environment. The Brundlandt report was a major wake-up call. Furthermore, the Kyoto Protocol and Paris Agreement are major stepping stones to mitigate the effect of climate change. But time marches on. Climate change is still today an urgent matter which needs our immediate attention.

Legislation to battle climate change is in place at European and national levels. In Europe, among others, the Energy Performance of Buildings Directive (EPBD) is implemented to reduce the impact of the built environment on climate change. The energy transition in the built environment is a key strategy to mitigate the impact of our daily life on the environment. Dutch non-profit housing associations own one-third of the dwellings in the Netherlands. Other European countries with a large share of social housing are Austria 24%, Denmark 21%, Sweden 17%, UK 17%, France 16%, Norway 14%, and Finland 11%. Due to the share of the stock, changing the non-profit housing stock plays a vital role in the transition to a future sustainable housing stock.

This research examines the energy performance of the housing stock of Dutch non-profit housing associations. The energy performance of dwellings can be defined as the quality of dwellings in relation to the actual energy consumption during the operation phase of the dwelling. The aim of European and national policy is to improve the energy performance, and therewith to lower actual energy consumption, by building new dwellings with a good energy performance and by renovating the existing housing stock.

Several scientific challenges appear in understanding and improving the energy performance of dwellings of Dutch non-profit housing associations. First, there is a need to monitor the progress of changes of the energy performance in the housing stock. Monitoring the energy performance of the housing stock helps in establishing a well-founded knowledge base, enabling the evaluation and adaptation of policies aimed at increasing the energy performance of the housing stock. Second, there is a need to improve theoretical calculations of the energy performance through modelling actual energy consumption. Currently, a performance gap exists between theoretical and actual energy consumption of dwellings. Improving the calculations helps in estimating the actual energy savings of renovations and in estimating the energy consumption of new dwellings. Third, there is a need to measure the energy performance of dwellings with heat pumps. Heat pumps are a promising solution for the future and gaining insights about different dwellings and systems helps in understanding the potential of heat pump systems in the Dutch non-profit housing stock. Fourth, there is a need to assist housing associations by benchmarking the energy performance of their housing stock in agreement with changes in policy after 2020. Creating a benchmark model helps in the measuring and evaluation of the energy performance towards a future sustainable

housing stock. The aim of this thesis is to cover these challenges by assessing and understanding the improvement of the energy performance of dwellings of non-profit housing associations towards a future sustainable housing stock.

The main research question of the study is therefore:

How to assess and understand the improvement of the energy performance of dwellings of non-profit housing associations towards a future sustainable housing stock?

This is operationalized with four studies:

- Study 1: Monitoring energy performance improvement: insights from Dutch housing association dwellings
- Study 2: The energy performance of dwellings of Dutch non-profit housing associations: modelling actual energy consumption
- Study 3: The energy performance of dwellings with heat pumps of Dutch non-profit housing associations
- Study 4: Benchmarking energy performance: indicators and models for Dutch housing associations

Study 1 assesses the energy performance progress between 2017 and 2020. It contributes to the understanding of the improvement of the energy performance of dwellings of non-profit housing associations by giving insights into the development of the housing stock, the effect of changes of and within the stock, the effect of characteristics of housing associations and by relating the improvement of the energy performance to the sectoral goal. Study 2 assesses models to estimate actual energy consumption of dwellings. It contributes to the understanding of the energy performance of dwellings of non-profit housing associations by giving insights into the extent to which advanced modelling of the energy consumption can improve the estimation of energy savings of renovation measures. Study 3 assesses the energy performance of dwellings with heat pumps. It contributes to the understanding of the energy performance of dwellings of non-profit housing associations by giving insights into the energy performance of dwellings with heat pumps as a promising renovation measure towards a future sustainable housing stock. Study 4 assesses the benchmarking of the energy performance. It contributes to the understanding of the energy performance of dwellings of non-profit housing associations by creating a benchmark model related to the changing policy context, therewith contributing to the understanding and improvement of the energy performance of dwellings of non-profit housing associations towards a future sustainable housing stock.

Research methods

Two main data sources are used to answer the research questions in this thesis, the Shaere-database and microdata of energy consumption on address-level from the Dutch Central Bureau of Statistics (CBS). The Shaere-database is a database of energy performance data and building characteristics of over two million dwellings of non-profit housing associations, collected annually under coordination of this research project and maintained by Aedes, the umbrella organization of Dutch non-profit housing associations. The

CBS collects and maintains an annual database of actual energy consumption of Dutch addresses, available in an anonymized analysis environment. The combination of these databases is the main basis for the studies performed in this thesis.

Several research methods are used to perform the four studies in this thesis. The collection of raw data, consisting of the energy performance and building characteristics of dwellings of non-profit housing associations is a basis for all studies. Studies 1 and 3, mainly consist of statistical analyses of raw data to answer the stated research questions. In study 2, besides raw data collection and statistical analysis, advanced modelling techniques are applied to reach the desired research results. A linear, a non-linear and a Gradient Boosting Model (GBM) are examined. In study 4, also raw data collections and statistical analysis were used, but action research where the researcher participated in group sessions with experts from non-profit housing associations is the main research method.

Results

Study 1, *monitoring energy performance improvement: insights from Dutch housing association dwellings,* helps to understand the improvement of the energy performance by which measures are taken and which potential is left to renovate or to replace with new construction. The research shows that the energy performance of dwellings of Dutch non-profit housing associations improved steadily between 2017 and 2020. The research shows that the effect of changes of the stock (construction and demolition) to the improvement of the average energy performance is modest (15.6%). The improvement of the average sectoral energy performance happens for 85.4% within the existing stock, mostly with traditional improvements like changing heating installations and adding insulation. The research shows that large urban housing associations drive the improvement of the average sectoral energy performance. The research concludes that the sectoral goal of an average energy-index of 1.40 in 2020 will not be achieved in the year 2020 but can be achieved at the end of 2021.

Study 2, *the energy performance of dwellings of Dutch non-profit housing associations: modelling actual energy consumption*, shows that modelling the actual energy consumption helps to understand the effectiveness of renovation measures in lowering actual energy consumption and related CO_2 emissions. The research shows a large performance gap between theoretical and actual energy consumption underlining the need for actual energy consumption modelling. However, the research shows that modelling the actual energy consumption of dwellings is challenging. The actual energy consumption was modelled with three different models, a linear regression, a non-linear regression and a GBM machine learning model. The research shows that the three different models have their own pros and cons. Linear regression models are simple and fast and estimate sectoral cross-sections very well but are not useful in analyzing the effects of detailed renovation measures. A non-linear model can estimate sectoral cross-sections and detailed renovations and uses the structure of actual consumption physics but is only able to use given relations between building features and will therefore not pick up on other relations which could improve the estimations of the effects of renovations. The non-linear model is easier to interpret, which could be a reason to prefer such a model above the other models. A Gradient Boosting Model is able to detect all kinds of relations between building features. It can find correlations and interactions that even specialists in the field are not aware of. However, the model does not use the structure of actual

energy consumption physics to its advantage. Therefore, it is more difficult to interpret the results and if some renovation measures (e.g. electrical heat pumps) occur less frequently in the dataset this can result in outcomes that are unrealistic. The research recommends that combining theoretical models with empirical calibrations (grey box models) could be used to enhance the accuracy of estimations of the energy performance.

Study 3, *the energy performance of dwellings with heat pumps of Dutch non-profit housing associations,* shows that a statistical analysis to assess the energy performance of dwellings with heat pumps helps to understand the potential of heat pump systems in the future Dutch non-profit housing stock. In the research, the characteristics and the average actual energy consumption of dwellings with heat pumps are determined and compared to dwellings with a traditional HR107 condensing gas boiler. 3.2% of the dwellings of non-profit housing associations operates with a heat pump, consisting of all-electric heat pump systems (1.2%), hybrid systems (0.8%), gas absorption heat pumps (0.6%), gas absorption hybrid systems (0.4%) and other configurations (0.2%). Dwellings with all-electric heat pumps have an average higher building quality, no gas consumption, and higher electricity consumption, as opposed to dwellings with hybrid or gas absorption heat pumps, which have an average higher building quality, lower gas consumption, and higher electricity consumption as opposed to dwellings with a traditional HR107 gas boiler. Detailed insights are provided for dwellings with different heat pump systems and for dwellings with different building characteristics.

Study 4, *benchmarking energy performance: indicators and models for Dutch housing associations,* shows that a model to benchmark the energy performance of Dutch non-profit housing associations can be created by following a structured approach. Benchmarking is a method that can be used to measure progress and to create awareness about the performance of organizations. The benchmark model helps to support housing associations to analyse and compare the energy performance of their housing stock in agreement with active policies. Other researchers aiming at benchmarking the energy performance between organizations within their policy context, can adopt and adapt this structured approach. The final policy performance model to measure and benchmark the energy performance of Dutch non-profit housing associations consists of three indicators closely related to active policies regarding the sustainable improvement of the Dutch non-profit housing sector: (1) The average theoretical primary fossil energy consumption, (2) the average distance to the maximum theoretical heating demand, and (3) the average actual CO2 emissions from gas consumption. The first indicator is related to the current policy regarding the energy labelling of dwellings, derived from the EPBD, the NTA8800. The second indicator relates to the policy to decrease the average theoretical heat demand of dwellings. The third indicator is related to the goal for the Dutch built environment to lower actual CO_2 emissions.

Conclusion and recommendations

The main research question of the thesis is: How to assess and understand the improvement of the energy performance of dwellings of non-profit housing associations towards a future sustainable housing stock? The studies performed in this thesis show that in order to assess the energy performance of non-profit housing associations a systematic data collection method is vital. The studies are based on the SHAERE database with the energy performance characteristics of over two million dwellings collected annually

and the actual energy consumption of those dwellings available in an anonymized environment at the Dutch Central Bureau of Statistics (CBS). To assess the data different analytical methods help to deliver insights. In this research, a monitoring system, advanced modelling techniques, statistical analysis of data, and a benchmark model are used. These techniques help to gain valuable insights to understand the improvement of the energy performance of dwellings of non-profit housing associations.

- Monitoring the energy performance progress helps to understand the improvement of the energy performance of dwellings of non-profit housing associations by giving insights into the development of the housing stock, the effect of changes of and within the stock, the effect of characteristics of housing associations and by relating the improvement of the energy performance to the sectoral goal.
- Using advanced modelling techniques to estimate actual energy consumption of dwellings contributes to the understanding of the extent to which a linear model, a non-linear model and a Gradient Boosting Model (GBM) can improve the estimation of the energy consumption of dwellings and therewith the energy savings of renovation measures.
- Assessing the energy performance of dwellings with heat pumps contributes to understanding the potential of heat pumps as a promising renovation measure towards a future sustainable housing stock.
- Benchmarking the energy performance contributes to the understanding of the energy performance improvement of dwellings of non-profit housing associations in relation to active policies.

The thesis recommends to continue the monitoring of the energy performance of dwellings in order to be able to assess and continuously understand the improvement of the non-profit housing sector towards a future sustainable housing stock. The thesis recommends to further improve the modelling of the actual energy consumption of dwellings to accurately measure the effect of renovations, with advanced grey box models as direction to further explore. The thesis recommends to determine the energy performance of dwellings with specific heat pump configurations, and the thesis recommends to start or continue to benchmark the energy performance across housing stocks, therewith unleashing the potential to learn from each other.

Finally, persistent efforts are needed, both in research and in practice, towards a future sustainable housing stock, therewith contributing to the battle against climate change, with the aim to preserve a healthy earth for future generations.