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Understanding the progress of sustainable urban development through energy performance

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Abstract. The development of energy efficient buildings has been identified as a crucial part of the challenge to reach climate targets. Energy performance requirements are one of the most concrete and actionable parts of the sustainability program of urban development processes. However, after construction, there is often a lack of evaluation and follow-up of the energy performance requirements for the buildings, which limits the understanding of the state and progress of sustainable urban development processes and the ability to capture lessons learned related to energy performance. The aim of this paper is to provide insight into how the actual energy performance of buildings relates to the development process of an urban district that has been developed with a high sustainability profile. The urban district of Kvillebäcken (Gothenburg, Sweden) is used as a case study. The results of this paper contribute to a better understanding of the efficiency of the energy performance requirement as a tool during the urban development process, taking the actual energy performance of the buildings as a starting point.

1. Introduction

Almost a third of the global final energy use and 28% of global energy-related carbon dioxide (CO_2) emissions can be related to the building sector [1]. The development of sustainable and energy-efficient buildings and urban districts is therefore a crucial part of the challenge to reach climate targets. In 2002, the European Union introduced the Energy Performance of Buildings Directive to promote energy efficiency in the building sector, which was revised in 2010. Since then, energy performance certificates have been developed as a core tool to improve energy efficiency, decrease energy use and provide more transparency on energy use in buildings [2].

In this paper, the focus is on the energy performance of new buildings in an urban district that has been developed with a high sustainability profile – where sustainability ambitions exceed regulations. Energy performance requirements are often one of the most concrete and actionable parts of the sustainability program of urban development processes. These requirements are determined in the early phases of the process and conveyed from the larger planning scales to the scale of the buildings in a later phase. Previous research on energy performance has often focused on the technical or material side of energy performance and on how to simulate results and design monitoring processes in relation to the energy performance of a building, seeing “human actors as sources of uncertainty, rather than as full participants in the complexity” [3, p. 471]. However, several authors have addressed the need to study energy performance in relation to the ways in which buildings are designed, constructed, and operated by building professionals [e.g. 4,5]. Collaboration among building professionals is seen as a way to improve energy performance of buildings [6]. So far, little attention has been given to the ways of working, collaborating, and the actual agreements related to energy performance in urban development processes, but these "can have a profound effects on building energy performance" [5, p. 7].

2. Aim and research design

The aim of this paper is to provide insight into how the actual energy performance of buildings relates to the development process of a district developed with a high sustainability profile. A case study was carried out in the urban district of Kvillebäcken in the city of Gothenburg (Sweden). This urban district was developed with an energy performance requirement of 60 kWh/m^2 per year. At that time, the energy performance requirement in the Swedish national building regulation was 90 kWh/m^2 per year [7]. The analysis focused on the development process from 2004 till 2019 and included the official follow-up of the process. The actual energy performance analysis was based on the energy performance certificates of the 21 residential properties in Kvillebäcken, issued between 2015 and 2020.

The main indicator for determining energy performance in Sweden is the primary energy number of a building (in kWh/m^2 per year). The primary energy number is calculated by multiplying the building's specific energy use with nationally defined weighting factors. Before 2019, the energy performance was based on the specific energy use of the building. Specific energy use includes annual energy supplied to a building for heating, comfort cooling, domestic hot water production and electricity for the operation of the building. Household electricity or electricity for business activities is not included. In Kvillebäcken, there are in total 21 residential properties. In this paper, residential property is defined as a plot of land with one or more residential building blocks, developed by a single developer. In Kvillebäcken, there are nine properties with an energy performance certificate from before 2019 and thirteen from after 2019, see figure 1. One residential property has an energy performance certificate from both before 2019 and after 2019. To compare the energy performance of the buildings, the energy performance based on specific energy use was used in this paper. The energy performance certificates that were issued after 2019 were therefore recalculated to specific energy use. When a property has more than one energy performance certificate, the average specific energy use was used. Next to the energy performance certificates, the energy performance calculations from the design phase were used in the analysis. Calculations for ten properties in Kvillebäcken were available in the building permit archive of the municipality of Gothenburg.

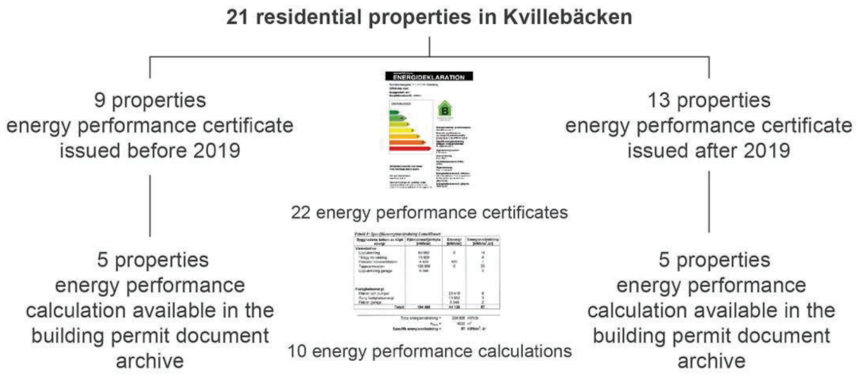

Figure 1. The differences in energy performance certificates and calculations for the properties in Kvillebäcken

The results were based on document analysis, semi-structured interviews with the developers, observations from a feedback meeting with the developers as well as quantitative data analysis of energy performance calculations and certificates. A detailed overview of the empirical material is given is table 1.

Table 1. Empirical material used in this paper

Empirical material	Year
Planning documents, including urban planning program, urban design program, detailed development plan, Kvillebäcken agreement and sustainability program	2002 - 2011
Building permit documents (including energy calculations of 10 properties)	2010 - 2014
Semi-structured interviews with the seven developers	2012
Observations from a feedback meeting with the developers	2013
Follow-up document of the sustainability plan of Kvillebäcken	2018
Follow-up document of the planning process of Kvillebäcken	2019
Detailed energy performance certificates of 21 properties in Kvillebäcken (issued between 2015 and 2019)	2020

3. Results

The results are divided into two parts. In the first part an analysis of the calculated and actual energy performance of the buildings in Kvillebäcken is presented and in the second part a description of the development process in relation to the energy performance requirement is given.

3.1. Actual energy performance of the buildings in Kvillebäcken

The analysis of the actual energy performance of the 21 residential properties in Kvillebäcken shows large differences for the different properties – ranging from a specific energy number of 33 kWh/m^2 to 90 kWh/m^2 per year, see figure 2. Only 24% (5 of 21) of the residential properties in Kvillebäcken fulfilled the energy performance requirement of 60 kWh/m^2 per year.

The ten energy performance calculations from the design stage show a predicted energy performance between 41 and 62 kWh/m^2 per year. It can be assumed that all residential buildings in Kvillebäcken had a predicted energy performance of around 60 kWh/m^2 per year or less, as this was required to obtain a building permit. The calculated energy performance was only achieved in two properties. The other eight properties show an energy performance gap between predicted energy performance and the actual energy performance. The gap between varies between 11% and 77%. The average energy performance gap for the properties with an available energy performance calculation is 33%.

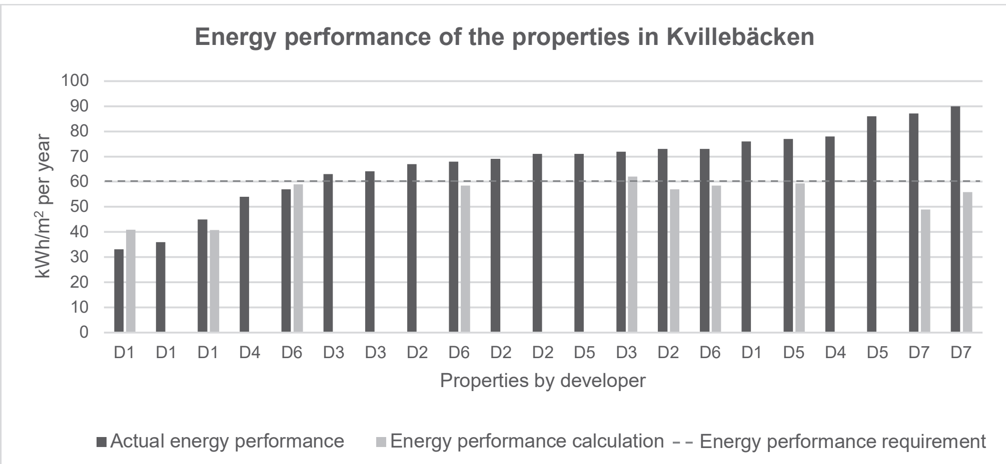

Figure 2. Actual energy performance and energy performance calculations of the properties in Kvillebäcken

In the next part of the results section, an analysis of the energy performance requirement during the development and follow-up process of Kvillebäcken is presented to provide a background to the differences in actual energy performance of the buildings in Kvillebäcken.

3.2. Energy performance requirement during the development and follow-up process of Kvillebäcken

The Kvillebäcken urban district is a redeveloped industrial site in Gothenburg (Sweden) and was marketed as a model for sustainable urban development. Around 2000 apartments and 24.000 m^2 of commercial spaces were developed on an area of 11.5 hectare between 2002 and 2019. The energy performance requirement for the buildings was set in the sustainability program for the district in 2011 at maximum 60 kWh/m^2 per year for all the buildings.

In 2002, the goals and starting points for the district were published in the urban planning program for Kvillebäcken. In this program, one paragraph was related to the sustainable urban development of Kvillebäcken and regarding energy, the focus was on the efficient use of the existing technical systems, including district heating. In 2004, the municipal development company of Gothenburg (*Älvstranden Utveckling*) was commissioned to coordinate the planning process. Next to the municipality, two developers (D1 and D2) were also landowners in the district. The development of Kvillebäcken started in 2007 with the urban design program and the detailed development plan. The urban design program stated that the entire district – of which Kvillebäcken was the first part to be developed – would be a showcase for sustainable urban development by 2025. In the final version of the detailed development plan (2009), the use of existing infrastructure, efficient energy use by reducing the heat demand and the concept of energy-efficient homes were mentioned in relation to sustainability and energy systems. Implementation started in 2009 and the three landowners in the district, D1 and D2 and the municipality of Gothenburg, organized a tendering process in which sustainability was an important part. The tendering process was won by another four other developers (D3, D4, D5 and D6). The land of the municipality was sold to a municipally owned housing company (D7) and together these seven developers and the municipal development company formed a consortium to develop the 24 plots in Kvillebäcken. Three plots had a commercial function, and 21 plots had a residential function. Public-private partnership was the intended mode of governance, and the idea was to work according to a model which was based on collaboration, common goals, and common responsibility within the consortium. Table 2 shows the type of developer and type of housing for the seven developers.

Table 2. Overview of the seven developers involved in the Kvillebäcken planning process

	Type of developer	Type of housing in Kvillebäcken	Number of properties in Kvillebäcken
D1	Private developer	Rental	4
D2	Private developer	Condominium	4
D3	Private developer	Condominium	3
D4	Private developer	Condominium	2
D5	Cooperative developer	Condominium	3
D6	Private developer	Condominium and rental	3
D7	Municipally owned housing company	Rental	2

In 2010 the Kvillebäcken agreement, including eight ambitions for a more sustainable built environment, was signed by the whole consortium, and was further developed into a sustainability program for the district. The sustainability program for Kvillebäcken (2011) brought together the requirements set by the municipality of Gothenburg in the program for environmentally friendly construction (2009), requirements from *Miljöbyggnad* (a Swedish system for environmental certification of buildings) and local requirements that were already in place for Kvillebäcken. The municipal program for environmentally friendly construction set a requirement of 60 kWh/m^2 per year with district heating or an alternative heating source with renewable energy. In addition, it was required that the energy performance would be followed up with an energy calculation in which the indoor temperature was set at 21 °C, submitted to the municipality for a building permit. The agreement was to certify all buildings in Kvillebäcken on *Miljöbyggnad* certification level silver, except for energy where level gold applied (60 kWh/m^2 per year). Next to the sustainability program, the development of Kvillebäcken was part of the government's initiative *Delegationen för Hållbara Städer*, in which the municipality of Gothenburg received a grant to make several efforts to promote sustainable urban development. The first concrete requirement for energy performance in Kvillebäcken was put forward in the sustainability program for Kvillebäcken (2011) as follows:

> Very energy efficient with a maximum energy performance of 60 kWh/m^2 per year. Added energy includes bioenergy through district heating, solar and wind energy. Individual metering and billing for residents will be installed.

Next to the energy performance requirement, more innovative energy solutions were developed as part of the above-mentioned grant. This project had the aim to test power-smart buildings, in which the buildings were used as short-term energy storage for a more efficient use of district heating. The idea was to test new technology to equalize the daily variation in district heating needs and to equip the buildings with appliances such as laundry machines, tumble dryers and dishwashers connected to district heating to reduce energy consumption [8].

In spring 2012, during the first construction phase, semi-structured interviews with the project leaders of the seven developers took place. The developers were asked about the implications of the sustainability goals for Kvillebäcken, focusing on the formulation, communication and understanding, implementation and the follow-up of the energy performance requirements. Although the consortium worked with a model which was based on collaboration, common goals, and common responsibility, several developers pointed out that in their experience the energy performance requirement came from the municipality since the municipal program for environmentally friendly construction had to be followed. They felt that they had no influence or say in the energy performance requirement for Kvillebäcken. By the time of the formulation of the requirements (2010/2011), the idea was that the energy performance requirement of 60 kWh/m^2 per year was too strict and difficult to reach, but at the time of the interviews (2012) most developers were convinced that they would accomplish the energy performance requirement. D5 explained that they used a strategy to understand the implications of the energy performance requirement by taking a previously developed building to see what measures could be taken to improve the energy performance. However, all developers still admitted that the energy performance requirement of 60 kWh/m^2 per year felt like a challenge as it was their first time working towards that requirement. D2 and D3 also pointed out that the energy performance requirements in Sweden differed from municipality to municipality and that they had worked with other requirements in, for example, Stockholm. Another concern was the different documents and programs used in Kvillebäcken and the order of 'power' or importance between the documents. The sustainability program for Kvillebäcken was intended as the document that brought the different documents together to make it easier and clearer. However, for some developers (D2 and D3) the sustainability program came too late in the process because they started designing the first buildings before the program came out. The actual implementation of the energy performance requirement revealed economic and organizational difficulties as well. According to D7, the investment costs to achieve an energy performance of 60 kWh/m^2 per year could not been recouped within fifty years, the lifetime with which they calculated. D1 indicated that it was difficult to obtain reasonable rents in Kvillebäcken due to the combination of the costs of remediation of the contaminated soil in the district and the investment required to meet the high energy performance. Three developers explained that it was difficult to implement more innovative ideas related to energy because of problems with collaboration and alignment of different actors, such as the municipality of Gothenburg, the municipal energy company, and the construction companies. Some requirements could not be met at all, for example the requirement to have laundry machines with energy classes A+ or A++ because there were no laundry machines on the market for shared laundry rooms with these energy classes.

By the time of the interviews, none of the developers made use of a structured way to follow-up energy performance during and/or after the development of the buildings in Kvillebäcken. They had no structures in place for knowledge management and said that it mainly existed between colleagues of the company. Three developers mentioned that they learned a lot from collaborating with the same architect or construction company for the development of the different residential properties in Kvillebäcken (D2, D4 and D6). D2 said that there was some form of learning after the buildings came into use when their aftermarket and customer service team took over the project for warranty. This team registered everything that comes in to anticipate warranty issues for new projects. D1, D4 and D6 expected more from the municipality in the following-up and reporting of energy performance requirements. Most of the developers indicated that there was some form of follow-up in the design meetings with the municipality, but not specifically related to energy performance.

In 2013, when the first phase of Kvillebäcken was nearly finished, an experience workshop with the developers and the municipal development company of Gothenburg was organized to see if lessons learned could be applied in the next phases of Kvillebäcken or in new projects. The main feedback from that workshop in relation to energy performance was the follow-up of the requirements. The overall conclusion was that tools for follow-up and steering were lacking. After the sustainability program came out, an Excel document with different color grades was developed for the different requirements. In this document the developers could show what they were planning to do in relation to the different sustainability requirements. According to the municipal development company, this served as a benchmarking tool and a driving force, but in the workshop the developers questioned the follow-up of the requirements and goals and the consequences of not meeting them. At that time, it was still not clear to them how the various documents, goals and requirements related to each other and what ambitions or requirements were. After this workshop, a new document was developed with an overview of the different requirements and which document was leading.

The next two phases were developed between 2013 and 2019. In 2018, the municipal development company published a follow-up document of the sustainability program in which lessons learned in relation to the eight ambitions of the Kvillebäcken agreement were shared. The actual energy performance of the buildings was not mentioned in the document, as it would be covered by the *Miljöbyggnad* certification system. The document showed that all buildings have been certified - not yet verified - to *Miljöbyggnad* level silver. However, an energy performance of 60 kWh/m^2 per year means level gold in the *Miljöbyggnad* certification system and that seemed to have been overlooked. The follow-up document of the entire development process was published in 2019. This document mentioned that a lot of time has been spent on sustainability monitoring, mainly through the *Miljöbyggnad* certification system, but that there was no systemic follow-up, and that this follow-up must also take place after the end of the project. Both follow-up documents stated that it proved to be difficult to set strict or ambitious goals and requirements at the beginning of the development process that remain up to date during the long process of urban development. What was at the forefront 10 to 15 years ago is today the new standard in most similar urban development projects.

4. Discussion and conclusion

The results of this paper showed that an urban development process with high sustainability ambitions and concrete energy requirements does not necessarily lead to buildings with the intended energy performance. The analysis of the energy performance certificates of the residential buildings in the urban district of Kvillebäcken (Gothenburg, Sweden) identified that only 26% of the properties fulfilled the energy performance requirement of 60 kWh/m^2 per year which was stated in the sustainability program for the district. Based on energy calculations from the design phase, an energy performance gap has been found between the predicted and actual energy performance that varies between 11% and 77%, on average 33%. The analysis of the energy performance requirement during the urban development process of Kvillebäcken revealed several challenges regarding the ways of working, collaborating and the actual agreements in relation to the energy performance requirement which could explain the differences in the actual energy performance and the energy performance gap of the buildings in Kvillebäcken. These challenges can be summarized in three interrelated themes:

Keeping information about the energy performance up to date during the process
The analysis of the urban development process showed that the energy performance requirement was clearly defined in the sustainability program for Kvillebäcken (2011), but that different information sources caused ambiguity and uncertainty about the focus and importance of the energy performance requirement during the process. In addition, the municipality indicated that it was difficult to keep the energy performance requirements up to date and ambitious during the relatively long development process. Several studies have shown that sustainability goals agreed during the first phase of a project are often lost and left behind when information is passed on to the next phases in the project [9–12]. Knowledge transfer during development processes proves difficult due to the long life cycle of a project, the phased approach from planning to implementation, people involved in the project who leave and new people who come in and the different iterations to plans [13,14].

Defining the roles of the different actors: expectations and responsibilities in relation to energy performance
The results of this paper pointed at some collaboration issues between the developers, the municipality, the energy company, and the construction companies which could be related to different expectations and unclear responsibilities during the different phases of the development process. There were no consequences for the developers for not reaching the energy performance requirements because after the control of the energy performance calculations for the building permit, the municipality left the full responsibility of reaching the energy performance to the developers. Previous research have shown that when projects come closer to the implementation phase, responsibilities are handed over from planning actors to implementation actors and the common vision is then replaced by the responsibility and way of working of each implementation actor [9,10].

Following-up the energy performance during and after the project
The results of this paper showed that most of the developers and the municipality had no structure in place for follow-up of the energy performance. Follow-up of energy performance requirements is crucial to understand the state and progress of sustainable urban development and energy efficient buildings and to capture lessons learned related to urban development and the energy performance of buildings [15–17]. Several other studies have also pointed out that after completion there is a lack of proper evaluation and control of the building's energy performance [18–21]. This lack of evaluation and control by the municipality and the developers could be seen as a major obstacle to achieve the energy efficiency targets and could become a major sustainability challenge [18,22].

Future research is needed to further understand and expand on these difficulties, for example by analyzing the roles and agency of the developers and the municipality regarding the energy performance of the buildings during the different phases of a sustainable urban development process, particularly during the final phases of a project [9].

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