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Active buildings in smart grids—Exploring the views of the Swedish energy and buildings sectors

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ABSTRACT

The development of smart grids is expected to shift the role of buildings in power networks from passive consumers to active players that trade on power markets in real-time and participate in the operation of networks. Although there are several studies that report on consumer views on buildings with smart grid features, there is a gap in the literature about the views of the energy and buildings sectors, two important sectors for the development. This study fills this gap by presenting the views of key stakeholders from the Swedish energy and buildings sectors on the active building concept with the help of interviews and a web survey. The findings indicate that the active building concept is associated more with energy use flexibility than self-generation of electricity. The barriers to development were identified to be primarily financial due to the combination of the current low electricity prices and the high costs of technologies. Business models that reduce the financial burdens and risks related to investments can contribute to the development of smart grid technologies in buildings, which, according to the majority of respondents from the energy and buildings sectors, are to be financed by housing companies and building owners.

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1. Introduction

Climate change as a result of the increasing concentrations of greenhouse gas (GHG) emissions in the atmosphere requires the reduction of the global use of fossil fuels, responsible for approximately 80% of the global GHG emissions [28]. Replacing the use of fossil fuels with renewable energy in power systems, however, remains a challenging task due to the intermittent nature of renewable energy resources, such as wind and solar. Current power systems have a highly centralised structure that only allows the uni-directional flow of power and information between generators and users, limiting the penetration of decentralised and intermittent generation from renewable energy resources into the networks [19,23]. Smart grids, operating on the principle of bi-directional flow of power and information, provide a higher degree of flexibility in power demand and supply and hence can accommodate larger amounts of renewables in the power networks [1,19]. The active participation of consumers, either by supplying energy and/or adjusting their energy use, plays a key role in the efficient operation of smart grids as also highlighted in the definition of smart grids by The European Commission Task Force for Smart Grids [17]:

> "A smart grid is an electricity network that can efficiently integrate the behavior and actions of all users connected to it—generators, consumers and those that do both—in order to ensure an economically efficient, sustainable power system with low losses and high quality and security of supply and safety"

It is expected that buildings, which represent approximately 40% of the energy demand both in the EU and in Sweden, contribute to the development and operation of smart grids by local energy supply and storage, energy demand flexibility, and real-time energy trade on power markets [18,31,41,47]. The transition to smarter power systems will shift the role of buildings from passive users to active participants that do not only use energy, but also act as suppliers who adjust their energy use to match the intermittent power production in the grid. Such shift may require the introduction of new technologies in buildings and accordingly the term "smart home" has been used to refer to buildings that integrate smart grid features, such as self-production of electricity, local energy storage, energy demand flexibility, and the automa-

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tion of energy activities. The same term, however, has also been used for buildings with features that are not necessarily related to energy which range from communication, comfort, entertainment, security, to even e-health services, such as elderly care [2,62].

Active buildings have emerged as a concept that particularly refers to buildings that are equipped with smart energy features. The Swedish Governmental Agency for Innovation Systems (Vinnova) and the Swedish Energy Agency, along with different private and public actors, funded the "Active building in the sustainable city" pilot project that involved the development of buildings with smart grid features in Stockholm Royal Seaport [63]. The active building in this project, as reported in Refs. [43], [44] and [51], combines the self-generation of electricity with active interaction with the energy network through user response to electricity prices and CO_2 emissions. There is, however, no consensus among researchers on this definition of the active building concept and its associated features. According to Isaksson [29], an active building has event-based heating, which involves adjusting the indoor temperatures based on household activities and the use of appliances. The active building concept in Ref. [16], on the other hand, focuses on self-sufficiency in energy use by local power generation and does not specifically address the interaction with the electricity grid.

In addition, despite the studies in the literature that present user views on smart homes, see Refs. [2], [30], and [40], there is also a gap in the literature about the views of the energy and buildings sectors, two key sectors for the development, on buildings with smart grid features. This paper aims to fill these gaps in the literature by exploring the active building concept through the perspectives of the energy and building sectors in Sweden and by presenting their views on smart grid features in buildings, barriers to their development, and the actor to make the investments.

2. Background

Sweden has one of the highest per-capita electricity consumption rates in the world with 14,000 kWh per person per year [64]. The deregulation of the Swedish electricity market in 1996 opened the generation and retail of electricity to competition although the transmission and distribution of electricity have remained as monopolies. Customers can purchase electricity from the retailer of their choice, but are still required to pay the distribution fees to their local electricity distribution company. Sweden joined Nordpool, the Nordic power market, following the deregulation and the country shares a common electricity certificate market with Norway.

Power generation in Sweden has low carbon-intensity with large amounts of hydropower and nuclear power (48% and 38%, respectively) as well as Combined Heat and Power (CHP) generation (10%) and wind power (4%) [54]. There is very small but steadily growing photovoltaic (PV) generation in Sweden, accounting for a mere 0.03% of the total domestic power demand [34]. The penetration of PV into the electricity grid is expected to increase following the introduction of tax reductions, in force as of 2015, on the surplus electricity that is fed into the grid by self-generators of electricity [56].

There are four and a half million households in Sweden, of which two and a half million are in one- and two-dwelling buildings and two million are in multi-dwelling buildings. In the multi-dwelling building sector, 60% of the dwellings are owned by housing companies, while the rest are owned cooperatively through housing associations, which are economical associations that provide housing to its members on a non-profit basis. In the one- and two-dwelling building sector, private owners stand for 92% of the dwellings whereas the rest are divided between housing companies and housing associations [50].

Sweden invests considerable efforts on the development of smart grids both through the introduction of the supporting regulatory framework and the organisation of pilot projects. Sweden was among the first European countries to complete the roll-out of smart electricity meters in 2009 [17]. In addition, Swedish end-users have been entitled to hourly metering of electricity free of charge since 2012 and a new proposal was put forward to further provide end-users with free of charge access to hourly consumption data [57]. The developments in smart grid and information and communication technologies, and the efforts to reach improved energy efficiency in the buildings sector, allowed Sweden to help consumers increase their knowledge of energy use.

Energy use visualisation is a proven method to influence household electricity demand [12,20]. One of the major projects carried out in Sweden, where different visualisation tools were tested, proved that households provided with in-home displays reduced their energy use by 10% [60] whereas the energy savings by the households provided with a dedicated web-site to track their use were around 15% [61]. The mentioned studies as well as others, such as [38], also prove that the type of information and the frequency of the feedback provided plays an essential role in user engagement, and hence in reducing energy use. The generally low electricity prices in Sweden, however, result that electricity savings are not regarded as a top priority by consumers, making "fit-and-forget" strategies a more suitable option when savings are needed.

There are several smart grid pilot projects in Sweden, developed cooperatively by different stakeholders that range from municipalities and universities to the members of the energy and buildings sectors. Some of the examples include the urban development projects Stockholm Royal Seaport and Hyllie that offer their residents smart grid features, such as user response to prices, home automation of energy activities, electricity price visualisation, among others [27,52]. Similar pilot projects have also been undertaken in the cities of Västerås and Falköping on a smaller scale [35–37]. Smart Grid Gotland, on the other hand, is a large smart grid project in Sweden which involves the development of a smart grid network on the island of Gotland in Southern Sweden. The project acts as a testing field for the deployment of smart grids in Sweden as Gotland is considered a small scale model of Sweden in 2030 when taking the future share of renewables into account [53].

3. Methodology

This paper presents the findings collected using semi-structured interviews and a web survey, answered by key stakeholders from the energy and buildings sectors in Sweden. In this paper, the energy sector is represented by respondents from district heating, electricity retail, and electricity distribution companies and the buildings sector is represented by those from construction and housing companies. As the focus of this study is to explore the perspectives of the stakeholders at a company level, private owners of buildings and housing associations are not included in this study.

This study combines the quantitative and qualitative data collection methods through the use of open-ended, close-ended, yes/no, and Likert scale questions in the semi-structured interviews and the web survey. The quantitative data presented in this paper was collected through the web survey whereas the qualitative data came from both the interviews and the web survey. The quantitative data from the web survey was also analysed statistically by one-way ANOVA and Tukey test at 90% significance level as well as by a Principle Component Analysis (PCA), as discussed more in detail in Section 3.3. Both the interviews and the web survey consisted of two themes; the first theme investigated the views of the energy and buildings sectors on energy use in buildings and inter-sectoral cooperation, while the second theme explored their perspectives on active buildings and the barriers to their development. Some of the results obtained from the interviews and the web survey were published previously in Refs. [8–10].

The majority of respondents held executive positions at the contacted companies at the time of the data collection and were therefore assumed to have sufficient knowledge to respond to the interviews and the survey. Given that this study investigated the views of the stakeholders, no personally identifiable data was collected from the respondents. Anonymous quotes by respondents, taken from the answers to the open-ended questions, were also included in this paper to complement the quantitative data and provide a better understanding of the perspectives of the stakeholders. Unless specified in the text, the quotes express the identified general views and do not reflect only the views of a single respondent. The quoted respondents are represented in the text by an acronym, signifying their background, and a number (e.g. DH1): DH, district heating; ED, electricity distribution; ER, electricity retail; H, housing; C, construction. An anonymised list of the quoted respondents in the text can be found in Appendix A.

3.1. Interviews

As part of this study, sixteen semi-structured interviews were conducted with employees from the energy and buildings sectors between November 2012 and June 2013. Semi-structured interviews allow flexible data collection by combining close-ended questions with open-ended questions, giving respondents the freedom to express their ideas in detail and help researchers to discover issues that may not have been covered in the interview guide [7,14,46]. The presence of an interviewer, however, may result in social desirability bias and distort the data [6,26]. Social desirability bias occur when a respondent answers the questions according to what is socially acceptable or desirable [66]. To reduce the impacts of social desirability bias on this study, the interview data was combined with the data collected from a web survey, which is deemed as a method that produces lower social desirability bias [25,32].

The interview respondents represent various stakeholders in the energy and buildings sectors, as shown in Appendix B. All interviews were conducted face-to-face, except four, of which three were conducted on the telephone and one by video conference. The interviews took approximately one hour to complete and were documented through note-taking on a computer, except one which was audio recorded digitally for later coding. All respondents were provided with reports based on the notes for checking to prevent misunderstandings and errors. A list of the interview questions is provided in Appendix C.

3.2. Web survey

A web survey was sent out in May 2013 to employees working at companies belonging to the Swedish energy and buildings sectors. Web surveys allow the time- and resource-efficient collection of large amounts of data, but create risks of sampling issues, i.e. in cases where the person answering the survey not belonging to the target population or there are multiple answers [65]. In order to minimise sampling issues, the respondents were contacted at their business e-mail addresses which were obtained from the official web-sites of the companies and the returned surveys were checked for multiple answers.

The web survey combined the interview questions with several additional questions, which were formed based on the knowledge gaps identified from the interview results. In order to understand the definition of the active building according to the stakeholders, the respondents were asked to specify the features that come to their mind when they hear the words “active buildings”. Following this, the respondents were provided with the following definition of the active building concept, created based on Refs. [43], [44] and [51]: “An active building participates in the efficient operation of the electricity network by energy demand flexibility, self-generation and storage of power. It provides real-time information about energy prices and related emissions as well as functions that allow manual or automatic energy management.”. The respondents were then asked to rate the features of active buildings based on their importance, specify the barriers to their development and name the actor to invest in the relevant technologies. A list of the survey questions is provided in Appendix D.

All the electricity retail, electricity distribution, and district heating companies operating at the time of sending the survey were contacted in order to accommodate the differences between different networks and companies. Given the vast number of companies in the buildings sector, a representative sample of housing companies from different regions of Sweden and the construction companies that had employee contact details available on the Internet were contacted. The companies that both construct and operate buildings were categorised as either “construction” or “housing” based on their core business activity. As the web survey included additional questions, the companies that responded the interviews have also been asked to answer the web survey. The web survey tool Netigate[1] was used to administer the survey.

The survey was sent out to 844 recipients and was answered by 338 respondents, resulting in a response rate of 40%. The number of respondents and the specific response rates by the stakeholder groups were as follows: district heating, 124, 43%; electricity distribution, 81, 40%; electricity retail, 46, 36%; construction, 45, 36%; and housing, 42, 45%.

3.3. Statistical analysis

The data collected from the web survey was statistically analysed to obtain further findings. Given that the aim was to investigate statistically significant differences between the responses by the stakeholder groups, only one of the questions, to which the answers were measured on an interval-level (i.e. on a scale of 1–5 corresponding to low–high), was eligible for the statistical analysis. Statistically significant differences in responses to “How would you rate the importance of the following features for buildings to become more ‘active’ in the energy system?” was first analysed by a one-way ANOVA followed by a post-hoc test (Tukey’s HSD multiple comparison). In order to explore statistical patterns that were not revealed by the ANOVA, a Principle Component Analysis (PCA) on the data was also performed.

An ANOVA involves computing the sums of squares and expected mean squares for all effects, which are then followed by a general linear model approach. ANOVA has been commonly used in the literature for statistically analysing survey data in a variety of scientific fields including energy research, such as in Refs. [10], [11], [13], and [61] to name a few. The ANOVA in this study was conducted on the software SPSS v. 22.0.0 (IBM SPSS Statistics Inc., Chicago, IL) and the alpha value in the analysis was set to 0.10, which corresponds to a significance level of 90%. The ANOVA results are presented in Table 1, where different letters (a and b) indicate the statistically significant differences in responses between the stakeholder groups.

The obtained results were also analysed by a multivariate approach to investigate the integrated effects by several different variables that may not be understood by analysing one variable at a time. Principle Component Analysis (PCA), the multivariate

[1] www.netigate.net

Table 1
The results of one-way ANOVA with Tukey ($p = 0.10$). The letters "a" and "b" indicate statistically significant differences in responses between stakeholder groups.

	Housing	Construction	Electricity distribution	Electricity retail	District heating
Self-generation of electricity	3.5	3.7	3.6	3.8[b]	3.2[a]
Local energy storage	3.4	3.4	3.2	3.6	3.2
User response to electricity prices	3.4[b]	3.3[b]	2.6[a]	2.9	2.9
User response to GHG emissions	3.8	4.2[b]	3.7[a]	3.6[a]	3.8
Electric vehicles for energy storage	3.2	3.0	3.0	3.5	3.0
Automation of energy activities	4.1	3.9	4.0	4.3	3.9
Visualisation of energy use	4.0	4.0	3.8	3.9	3.9
Smart systems that assist in energy-related decisions	4.2	4.1	3.9	3.7	4.1

approach used in this study, allows a visual representation of relationships between samples and variables, revealing patterns that may not be easily noticed when looking at large data sets. PCA has been used by researchers in both energy research [10,24,61] and in other fields of science [5,21,49,59] to analyse survey data. In PCA, a large data of possibly correlated variables are transformed to a smaller number of latent variables that are called Principal Components (PCs). The results are presented as scores, which describe the data structure in terms of sample patterns, and loadings, which describe the data structure in terms of variable contributions and correlations. The Unscrambler X v. 10.0.1 (CAMO Software AS, Norway) software was used to conduct the PCA in this study.

4. Results and discussion

4.1. What is an active building?

In order to understand the perceptions of the stakeholder groups regarding the active building concept, the respondents were asked "Which of the following do you think of when you hear the words 'active building'?". The respondents were provided with a set of pre-defined answers and were allowed to make multiple selections. The pre-defined answers included "Don't know" and "Other" options, of which the latter allowed respondents to provide free-text answers for specifying features that were not included in the list. The results presented in Fig. 1 show that the most prominent features that are associated with active buildings by the stakeholder groups are "automation of energy activities", "interaction with the energy system", and "flexible electricity use". Based on the results, it is possible to say that the energy and buildings sectors share a similar understanding of the active building concept despite some minor differences between the responses by the stakeholder groups.

According to some respondents, active buildings *"automatically control lighting, heating, ventilation, and electrical appliances for owners to reduce energy costs and for energy companies to make use of their resources in a better way"*ED1. The survey results, presented in Fig. 1, show that the most associated feature with active buildings by the stakeholder groups is "automation of energy activities", which was selected by more than 60% respondents from each stakeholder group. The interview results, however, suggest that the perceived concept of automation of energy activities by the respondents may not necessarily involve trading energy automatically with the energy network based on price or emission signals, but may only refer to the automation of energy management to achieve energy savings.

The results, presented in Fig. 1, show that more than 40% of respondents from all stakeholder groups associate "interaction with the energy system" with active buildings. A respondent explains how active buildings interact with the energy system with the following comment: *"For us, a building is like a piece of puzzle in a larger system. An active building is not a building that operates on its own, but it communicates with other [active] buildings and the central [energy] system. The central system might tell the building to regulate the demand after the price and try to shift the load to times of low demand. These puzzle pieces [active buildings] communicate with each other and act collectively in times of low production and high demand. Certainly, an active building can also be a producer of electricity"*DH1. Accordingly, "flexible electricity use" is another prominent feature that was associated with active buildings by the stakeholder groups as considerable shares of respondents from all stakeholder groups, especially from electricity retail and construction companies, selected this answer. Respondents express that active buildings *"actively respond to price and emission signals and use energy when it is cheaper or leads to lower CO_2 emissions"* ED2. A respondent from a construction company explains the positive impacts of active buildings on the electricity system with the following comment: *"The more active buildings we have in the electricity system, the flatter the [electricity] demand curve becomes. This way, we can help energy companies tackle peak loads"*C1. It is displayed in Fig. 1, however, that neither "user response to electricity prices" nor "user response to GHG emissions" are among the prominent features that are associated with active buildings by the stakeholder groups.

"Environmentally friendliness" is another feature that is closely associated with active buildings by the stakeholder groups, although the share of respondents that selected this answer varies from around 30% among construction companies to more than 60% among electricity distribution companies. It was not possible to identify a common understanding of what "environmentally friendliness" means for different stakeholder groups as the results suggest that the respondents associate several green technology features with active buildings, ranging from solar power and heat generation systems to construction materials that have lower environmental impacts. Respondents from the energy sector mentioned that the lower environmental impacts of active buildings come from energy demand flexibility, reducing the need for carbon-intensive peaking generation whereas the buildings sector mainly argued that active buildings have lower life cycle environmental impacts with some respondents saying that they may feature green roofs to further contribute to urban sustainability. It can be implicated from the results that the energy sector focuses more on the environmental impacts of energy use in buildings, while the buildings sector is concerned more about the overall environmental impacts of buildings, from construction to demolition phases, including those originating from energy use in buildings.

Some respondents describe active buildings as buildings that supply more energy than they use and feed surplus energy into electricity grids. The results presented in Fig. 1 suggest that "self-generation of electricity" is another feature that is associated with active buildings although the shares of respondents that selected this answer vary between the stakeholder groups. Similarly, the results also show that not all stakeholder groups associate "local energy storage", an often accompanying technology to self-generation systems, with active buildings as more than 40% of respondents from electricity distribution companies selected this answer in contrary to less than a mere 10% from housing companies.

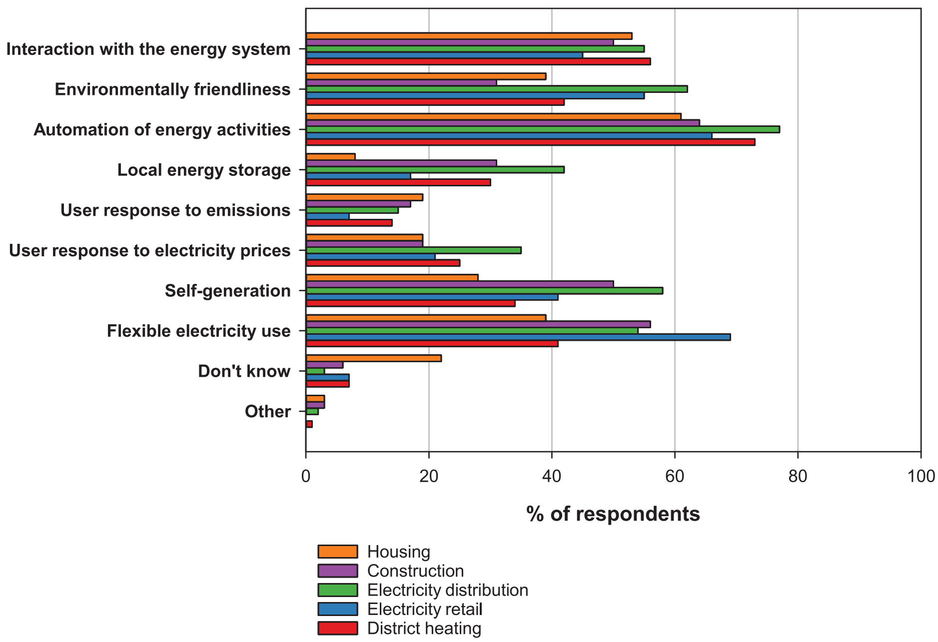

Fig. 1. Answers to the question "Which of the following do you think of when you hear the words 'active building'?" by stakeholder groups.

Only six respondents answered "Other", of which three commented on the environmental performance of active buildings by arguing that active buildings can only be considered environmentally friendly if they use electricity in times of low demand, referring to energy demand flexibility. Another respondent commented that *"an active is a building that supplies more energy than it produces on an annual basis"*H1, while two respondents described active buildings as *"low-energy"*DH2 buildings with *"good insulation"*ER1.

4.2. Active building features

The respondents were asked "How would you rate the importance of the following features for buildings to become more 'active' in the energy system?" and were given eight pre-defined smart grid features in buildings as displayed in Table 1 and Table 2. The most important active building features, according to stakeholder groups, are "smart systems that assist in energy-related decisions", "automation of energy activities", "visualisation of energy use", and "user response to electricity prices".

The ANOVA results, presented in Table 1, suggest statistically significant differences in responses between certain stakeholder groups, indicated by the letters "a" and "b", for the features "self-generation of electricity", "user response to electricity prices", and "user response to GHG emissions". The implications of the ANOVA are discussed under each of these features in the following sections.

4.2.1. Smart systems that assist in energy-related decisions

Decision support systems can help customers actively manage their energy activities by providing them with necessary information to take decisions, contributing to the efficiency of smart grids [48]. The results show that "Smart systems that assist in energy-related decisions" are considered the most important feature of active buildings by the respondents. Table 2, showing the distribution of responses by the stakeholder groups, suggests that housing, district heating and electricity distribution companies are the most positive towards smart systems that assist in energy-related decisions. These three stakeholder groups were identified to be impacted the most from peak energy demand by buildings [9,10] and the results can be interpreted as support for change in energy use patterns through information. A respondent from the energy sector points out the importance of receiving energy advices based on personal energy activities: *"Receiving [energy] advices is very important. Today, there are usually more general energy advices; they need to be tailor made for customers."*DH1.

4.2.2. Automation of energy activities

Automation of energy activities in buildings can contribute to the operational efficiency of smart grids and maximise the economic benefits for consumers that respond to time-variable tariffs [45]. Paetz et al. [40] reports positive customer views on home appliances that operate automatically when electricity prices are low. Our results suggest that the stakeholder groups consider the automation of energy activities the second most important feature of active buildings.

Illustrating the distribution of the responses by the stakeholder groups, Table 2 suggests strong support for automation by electricity retail companies, while a somehow weaker support was identified among the construction companies. The results suggests a reluctance to high levels of automation in buildings by the construction sector as pointed by a respondent: "*These [active] apartments switch off the lights 5 minutes after you leave the room and there are sensors everywhere that track your movements. The question is do we really want to have this technology?"*C2. The identified factors behind this reluctance were concerns over technical difficulties that may arise in the operation phase and the high costs of such systems, which naturally impacts the overall construction costs. Given that construction companies do not operate buildings, and hence do not receive the economic benefits from the systems, they may find it risky to invest in automation technologies.

Some respondents also pointed out that the customer interest for automation is low due to a combination of low electricity prices and high costs of systems: *"Electricity prices in Sweden are too low to motivate customers to invest in such [automation] systems or use it"*DH1. The study by Paetz et al. [40] reports that despite the positive customer attitude towards smart appliances, their high costs remain a barrier to adoption. In addition to high costs, a number of respondents expressed that people may be reluctant to 'hand over the control' of their homes and feel that too much automation intervenes with their privacy. Loss of control was also identified as a social barrier to the development of smart homes in Ref. [2].

Table 2
Answers to the question "How would you rate the importance of the following features for buildings to become more 'active' in the energy system?" by stakeholder groups for the sub-questions "Smart systems that assist in energy-related decisions", "Automation of energy activities", "Visualisation of energy use", "User response to electricity prices", "User response to GHG emissions", "Self-generation of electricity", "Local energy storage", and "Electric vehicles for energy storage". The highest share of respondents by stakeholder groups for each sub-question are marked in bold.

		Construction (%)	Housing (%)	Electricity distribution (%)	Electricity retail (%)	District heating (%)			Construction (%)	Housing (%)	Electricity distribution (%)	Electricity retail (%)	District heating (%)
Smartsystems that assist in energy-related decisions	**5–highest**	**36**	31	24	26	30	***User response to GHG emissions***	**5–highest**	14	11	5	4	3
	4	33	**47**	**54**	**33**	**51**		**4**	28	25	15	15	**33**
	3	25	8	14	22	11		**3**	**31**	**36**	**31**	**44**	29
	2	0	3	5	15	4		**2**	25	8	31	33	18
	1–lowest	0	0	3	0	1		**1–lowest**	0	3	15	0	12
	Don't know	6	11	0	4	3		**Don't know**	2	17	3	4	5
Automation of energy activities	**5–highest**	28	28	31	37	23	***Self-generation of electricity***	**5–highest**	28	17	20	**30**	13
	4	**36**	**42**	**49**	**52**	**48**		**4**	**36**	**33**	**41**	**30**	**30**
	3	25	17	12	4	20		**3**	19	22	25	**30**	25
	2	3	3	3	4	6		**2**	11	14	12	7	13
	1–lowest	3	0	3	0	0		**1–lowest**	6	3	2	0	12
	Don't know	5	10	2	3	3		**Don't know**	0	11	0	3	7
		Construction (%)	Housing (%)	Electricity distribution (%)	Electricity retail (%)	District heating (%)			Construction (%)	Housing (%)	Electricity distribution (%)	Electricity retail (%)	District heating (%)
Visualisation of energy use	**5–highest**	33	28	28	26	22	***Local energy storage***	**5–highest**	17	6	9	22	11
	4	**36**	**42**	**38**	**41**	**53**		**4**	28	**42**	**37**	**26**	28
	3	25	14	22	26	16		**3**	**36**	22	23	22	**32**
	2	3	6	5	4	5		**2**	8	19	28	19	16
	1–lowest	3	0	6	0	2		**1–lowest**	6	0	3	0	7
	Don't know	0	10	1	4	2		**Don't know**	5	11	0	11	6
User response to electricity prices	**5–highest**	33	25	22	7	20	***Electric vehicles for energy storage***	**5–highest**	6	11	9	7	13
	4	**56**	**36**	**38**	**56**	**47**		**4**	25	19	22	**45**	21
	3	11	22	29	22	19		**3**	**36**	**31**	**37**	33	24
	2	0	0	6	11	6		**2**	17	19	23	11	**25**
	1–lowest	0	6	5	0	3		**1–lowest**	8	3	9	0	9
	Don't know	0	11	0	4	5		**Don't know**	8	17	0	4	8

4.2.3. Visualisation of energy use

Visualisation of energy use is an effective way to influence energy behaviour [60]. Our results suggest that visualisation of energy use is considered the third most important feature of active buildings by the respondents, although it is not possible to observe significant differences between the responses by the stakeholder groups, as shown in Table 2. Many respondents think that visualisation of energy use is instrumental to making energy 'more visible' for influencing energy use patterns. Some respondents, however, argue that not many people are interested in keeping track of their energy use, as pointed out by a respondent: *"Our customers can log-in and see their energy use on the internet, but only 4% or 5% of them actually use it"*DH1. Some respondents, on the other hand, suggest that mobile applications are more effective than in-home displays and websites for capturing the interest of people: *"Simple numeric visualisations are no longer interesting [for consumers], but mobile applications are."*C1.

4.2.4. User response to electricity prices

Variable tariffs can create incentives for consumers to adjust their energy use based on electricity prices, also called demand response, on which Bartusch and Alvehag [3] and Bartush et al. [4] reported positive customer views in Sweden. Our results suggest that the energy and buildings sectors consider "user response to electricity prices" one of the important features of active buildings. However, the responses vary between stakeholder groups as shown in Table 2, showing that construction companies are the most positive stakeholder group towards "user response to electricity prices" as an active building feature whereas electricity distribution companies came out somehow more negative, as also confirmed by the ANOVA results (Table 1). Respondents from electricity distribution companies mentioned that the current *"tariffs for customers are not dynamic enough to create price differences and provide significant benefits"*ED3, suggesting that weak incentives for energy demand flexibility in Sweden can be the reason behind their less favourable view on user response to electricity prices. The role of electricity prices in active building developments is addressed in Section 4.4 of this paper.

4.2.5. User response to GHG emissions

Environmental concerns are among the incentives for customers to participate in demand side flexibility [22]. However, our findings suggest that "user response to GHG emissions" by the consumers is considered the least important feature of active buildings by the stakeholder groups. It is possible to identify differences between the responses by the stakeholder groups by looking at Table 2, which suggests that stakeholders representing the buildings sector are more positive towards user response to GHG emissions in active buildings than those from the energy sector. The ANOVA results, displayed in Table 1, particularly suggest that construction companies are the most positive stakeholder group, in contrary to electricity distribution and electricity retail companies, which are the most negative towards "user response to GHG emissions". Some respondents from the energy sector argued that *"there are a few people that are interested in emissions as most people care more about prices."*DH1, explaining their somehow more negative view towards this technology. Gyamfi and Krumdieck [22] also report that economic benefits create stronger incentives than environmental concerns for customers to voluntarily move their energy demand.

4.2.6. Self-generation of electricity

Buildings integrated in smart grids are often considered to feature small scale renewable energy systems for self-generation of electricity [40,48]. However, the findings of our study suggest that self-generation of electricity is not considered an important feature of active buildings by the energy and buildings sectors, although it is possible to identify differences between the responses by the stakeholder groups.

Both Table 2 and the results from the ANOVA that is presented in Table 1 suggest that electricity retail companies are the most positive stakeholder group towards "self-generation of electricity" as an active building feature whereas district heating companies came out as somehow more negative. Bulut et al. [10] reports that Swedish electricity retail companies are positive towards the self-generation of electricity in buildings, which they consider a business opportunity. These expectations can be the reason behind the support by electricity companies for self-generation of electricity as an active building. The reason behind the somehow more negative view by district heating companies may be related to that self-generation systems can be combined with heat pumps for increased self-sufficiency, reducing the district heat demand.

4.2.7. Local energy storage

PV systems can be combined with batteries and hot water tanks (e.g., if combined with electric heating) to increase the levels of self-consumption and energy demand flexibility in buildings [58]. However, our results suggest that "local energy storage" is not considered an important feature of active buildings by the respondents. Nevertheless, Table 2 shows that housing and electricity retail companies are somehow more positive towards "local energy storage" than the other stakeholder groups, especially district heating companies. Commenting on the Swedish case, a respondent said that *"today, self-generation [of electricity] is so small that there is no need for local energy storage."*DH1.

4.2.8. Electric vehicles for energy storage

The use of electric vehicles for energy storage can significantly improve the self-sufficiency of buildings [33]. However, similar to local energy storage, the results suggest that the respondents do not consider "electric vehicles for energy storage" an important active building feature. Although, there is somehow stronger support for this feature among electricity retail companies, as shown in Table 2, which can be a result of their expectations of higher electricity sales. Some respondents point out that electric vehicles *"would gain importance in the future if there is a huge development in terms of the expenses and batteries"*DH1, hinting that although they are not considered an important feature of active buildings today the situation may change depending on the technological developments. Respondents from electricity distribution companies, however, warn that it could be challenging to accommodate a large number of electric vehicles in the electricity network, which may create difficulties for electricity distribution companies.

4.3. Multivariate approach

Responses to the question "How would you rate the importance of the following features for buildings to become more 'active' in the energy system?" were additionally analysed by a PCA, which produced the scores and the loadings plots, presented in Figs. 2 and 3, respectively. The scores plot displays how different respondents are related to each other based on their responses and hence is an effective tool to visualise the similarities and differences between the perspectives of the stakeholder groups. No clear patterns can be detected in the scores plot which indicates that the responses were dispersed and the respondents within specific categories did not follow a specific trend in how they answered the question that was analysed. It is possible that more distinctive groupings would have been visualised in the scores plot if a scale with a larger interval, such as a 7-point Likert scale, had been used in this question. However, an important finding from the score plot is that the responses by the different stakeholder groups were somehow similar.

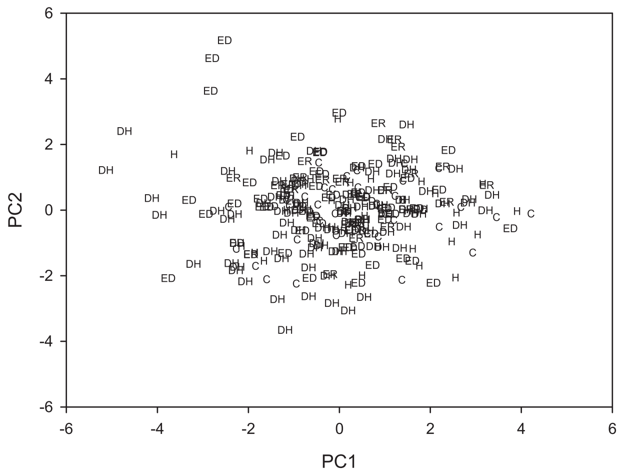

Fig. 2. The scores plot produced by the PCA, showing how different responses are related to each other based on their answers to the survey question. The abbreviations used in the scores plot as are follows: DH, district heating; ER, electricity retail; ED, electricity distribution; C, construction; H, housing.

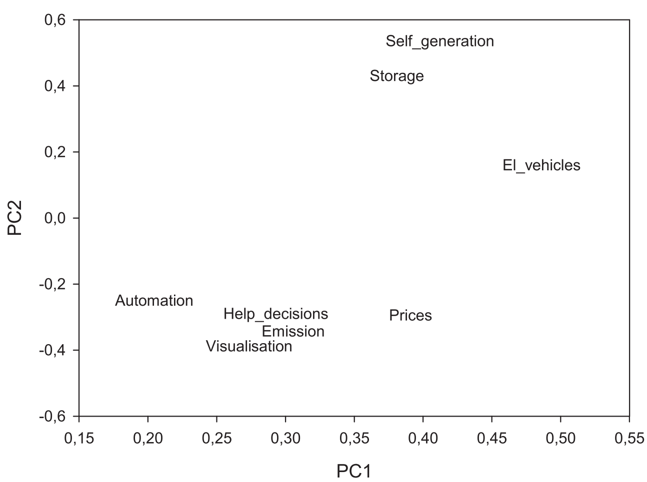

Fig. 3. The loadings plot produced by the PCA, showing the correlations between the active building features based on the answers to the survey question. The abbreviations used in the loadings plot are as follows: "Automation", automation of energy activities; "Visualisation", visualisation of energy use; "Prices", users response to electricity prices; "Emission", user response to greenhouse gas emissions; "Help_decisions", smart systems that assist in energy-related decisions; "El_vehicles", electric vehicles for energy storage; "Storage", local energy storage; "Self_generation", self-generation of electricity.

The loadings plot, presented in Fig. 3, displays the correlations between the active building features based on the responses received. The features that are grouped together in the loadings plot are closely correlated to each other whereas those that are located far apart are less correlated. The loadings plot shows that the respondents answered similarly to "self-generation of electricity" (Self_generation) and "local energy storage" (Storage) as the two features are grouped together in Fig. 3, confirming that the two are complementing technologies. In addition, it can be also perceived that the stakeholder groups do not necessarily associate energy demand flexibility with self-generation and storage of electricity; self-generation and storage of electricity are located far apart from the features that target energy demand flexibility which are at the bottom left corner of the plot. Although located somehow close to the "self-generation of electricity" and "local energy storage" features, "electric vehicles for energy storage" (El_vehicles) appears not to be related to the rest, suggesting that electric vehicles are not considered as a means of storage or a related active building feature at this stage of development.

The loadings plot in Fig. 3 shows that the features "visualisation of energy use" (Visualisation), "smart systems that assist in energy-related decisions" (Help_decision), and "user response to GHG emissions" (Emission) are closely correlated with each other, suggesting that the respondents consider systems that visualise energy use and provide recommendations to consumers based on their environmental impacts as a combined technology. Such systems can be complemented with the two other related features, "user response to electricity prices" (Prices) and "automation of energy activities" (Automation), which are located a little further, as shown in Fig. 3.

4.4. Barriers to the development of active buildings

In order to investigate the barriers to the development of active buildings, the survey respondents were asked "Which of the following factors do you think that negatively impact the development of 'active buildings' in Sweden?" and were provided with a set of pre-defined answers, from which they were allowed to make multiple selections. The pre-defined answers included "Don't know" and "Other", and the respondents that selected "Other" were displayed an additional question in the next page asking them to specify the factors that were not listed by entering their answers in the form of free-text. The results in Fig. 4 suggest that "high investment costs", "low energy prices", and "regulatory framework" are considered the most significant barriers that hinder the development of active buildings in Sweden.

According to the results illustrated in Fig. 4, a strong majority from all stakeholder groups consider "high investment costs" as the most significant barrier to development of active buildings, with the share of respondents that answered such reaching as high as 95% among electricity distribution companies. Respondents express that the prices of active building components are high, which they cite as the most significant barrier to development. Some respondents find the "lack of standardisation of technologies" as one of the factors that contribute to the high prices, arguing that technology suppliers monopolise the market: *"A major problem in the development is that there is no standardisation and commercialisation of the components, which would reduce the prices and make these technologies more competitive and widely available."*H2. In fact, the results show that more than quarter of respondents consider the "lack of standardisation of technologies" a barrier to the development of active buildings, as also displayed in Fig. 4. The share of respondents that selected this answer was particularly higher among electricity distribution companies with 40%. The results show similarities to the findings presented in Refs. [2] and [40], which reported that the high costs of smart homes are considered a barrier to their adoption by consumers.

Referring to smart electronic devices and home automation systems, some respondents argue that *"the technical solutions [used in active buildings] are quite immature/under development"*ED2, which, according to these respondents, impacts the commercialisation of the technologies and contribute to their high costs. It can be observed in Fig. 4 that approximately one-third of respondents from all groups think that "undeveloped technologies" is a barrier to the development of active buildings. In fact, several technical difficulties encountered in one of the pilot projects in Sweden have been reported in the media [39].

According to the results presented in Fig. 4, "low energy prices" is considered one of the prominent barriers to the development of active buildings by the stakeholder groups. It is interesting to note that the share of respondents that selected "low energy prices" is significantly lower in the buildings sector than in the energy sector, suggesting that many companies in the buildings sector do

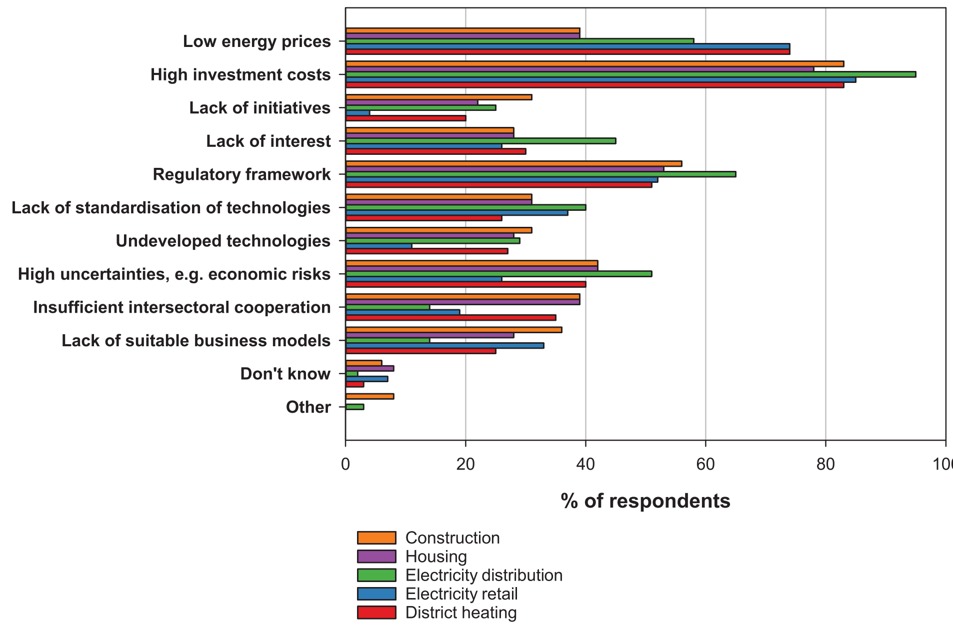

Fig. 4. Answers to the question "Which of the following factors do you think that negatively impact the development of 'active buildings' in Sweden?" by stakeholder groups.

not consider energy prices to be low. Some respondents argue that current electricity prices in Sweden are too low to attract interest in active building systems as, according to the respondents, low energy expenses combined with a high per-capita income negatively influence the public interest in energy-related issues. In additional regard to low electricity prices, respondents point out that the economic feasibility of investments is low due to weak incentives, which combined with long pay-back periods, create high levels of uncertainty. In fact, many respondents consider "high uncertainties" a significant barrier to the development of active buildings, as illustrated in Fig. 4. Respondents argue that *"what levels of risks [the investors of active buildings are subjected to] are one of the major factors to be taken into account"*ED1 regarding the development of active buildings, pointing that higher risks result in weaker interest to invest in active buildings. Some respondents comment that there is lack of suitable business models, which can both reduce the risks for end-users and financially encourage them to invest in active building technologies. Fig. 4 shows that especially respondents from construction, housing, and electricity retail companies, from which the share of respondents are as high as approximately 35%, consider the lack of suitable business models as a barrier to the development of active buildings. One of the respondents from a construction company comments: *"I hope that the existing big actors, such as real estate and energy companies etc., also understand the opportunity here [with active buildings] and change their business models"*C1.

Another significant barrier to the development of active buildings, according to Fig. 4, is "regulatory framework". At the time of conducting the survey, there was no support scheme for feeding electricity into the grid for self-generators, therefore several respondents pointed that a lack of support scheme for self-generation creates regulatory barriers to the development of active buildings. The results show that the share of respondents that selected the answer "regulatory framework" is higher among electricity distribution companies compared to other stakeholder groups. The reason behind this is that the current regulations in Sweden prevent the discrimination between customers by imposing that all customers of the same category in a network are offered uniform tariffs [55]. Due to this, electricity distribution companies are not allowed to offer special tariffs or demand response schemes to a specific group of customers, who may have a larger potential for energy demand flexibility, resulting in weaker incentives for consumers to change energy behaviour. Respondents from electricity distribution companies also confirm that the current regulations limit the introduction of new tariffs to provide stronger incentives for energy demand flexibility and argue that *"a more open way to test new tariffs could pave the way for the stronger development of active buildings"*ED2.

Bulut et al. [9,10] reports insufficient levels of cooperation between the energy and buildings sectors in Sweden. The results show that considerable shares of respondents from construction, housing, and district heating companies consider "insufficient intersectoral cooperation" one of the barriers to the development of active buildings. The respondents expressed that the effective cooperation between different sectors, especially the energy and buildings sectors, can be beneficial for the development: *"If we [the energy and buildings sectors] do not work together, we will not see much development."*DH3.

Low consumer interest in smart grids creates barriers to the development of smart grid technologies in buildings [15]. Fig. 4 suggests that many respondents, especially from electricity distribution companies, also consider "lack of interest" in active buildings as a barrier to the development of active buildings. Some respondents argue that many consumers do not have enough knowledge of their energy use and energy-related issues, and therefore they may not be interested in active buildings. A respondent from an electricity distribution company comments: "*A regular end-user does neither understand their energy use nor how the energy market functions. For example, it can be pretty hard for an end-user to know the difference between kW and kWh. I think the terms kW and kWh are not as easy to understand as a litre of gasoline. Therefore, it is hard for end-users to have an understanding of how much energy they use*"ED2.

Some respondents argue that there is "lack of initiatives" for the development of active buildings, both at a governmental level and a commercial level, and point out that *"pilot projects and research can be good for introducing the [active building] technologies"*ER1. The results displayed in Fig. 4 suggest that lack of initiatives is especially considered a barrier to the development by construction companies, from which approximately one third of the respondents selected this answer. This may be interpreted as a sign of interest by construction companies to participate in collaborative smart grid initiatives.

There were eight respondents that selected “Other” and provided their answers in the form of free-text. Two of the respondents expressed that active building technologies are too complicated for end-users, who, according to the respondents, would like to have simpler solutions. One of the respondents pointed out that there are weak incentives for end-users to invest in active buildings, while another respondent indicated that *“prices are the most important [factor]”*DH4. Touching upon the costs of technologies, another respondent answered that the high taxes imposed on imported technologies, such as PV cells, negatively impact the development. Two of the respondents cited lack of public interest as a barrier, while another respondent answered that there are too many business models but did not provide further clarification.

4.5. Who should make the investments?

Given the high costs of the technologies and long payback times, it is not clear who should finance and hold the ownership of the systems that support active buildings. The question of ownership is especially relevant to rental buildings and flats as there is little incentive for renters to undertake such investments. In order to understand the perceived actor by the stakeholder groups to make the investments for active buildings, the respondents were asked “Who do you think should invest in the infrastructure that supports more active buildings?” and were provided with the following predefined answers: “Building owner/housing company”; “Electricity retail companies”; “Third party suppliers”; “Technology suppliers”; “Electricity distribution companies”; “Other”; and, “Don’t know”. The respondents were allowed to select only one answer and those who answered “Other” were directed to another page where they were asked to provide their answers in the form of free-text

The results suggest that the majority of respondents think that “building owners or housing companies” should be the actors to invest in active buildings. Approximately half of respondents from electricity distribution companies answered such, followed by 40% of respondents from district heating companies. The majority of housing companies, accounting for more than 35% of respondents from this stakeholder group, also answered similarly, signalling their interest in active buildings. Referring to the ownership issues related to the rental sector, a respondent from a housing company comments: *“We, as the housing company, have to provide them [active building features] and pay for the costs.”*H3. Some respondents suggest that, in order to reduce the investment costs, housing companies or building owners provide the basic infrastructure and tenants purchase the additional features of their choice: *“There should be a simple system, where tenants can add desired applications and pay for the services that they wish to use, such as extra sensors. It is very hard for a person to buy the whole infrastructure.”*C1.

According to the results, the perceived actor to invest in active buildings, following building owners and housing companies, are “electricity distribution companies”. Construction companies have the highest share of respondents that selected this answer, exceeding more than 40% of respondents. Given that the distribution network owners are considered one of the primary beneficiaries of smart grid developments, they are expected by some respondents to invest in systems that support active buildings. It is interesting that electricity distribution companies do not share the same opinion as the share of respondents from this stakeholder group came out as the lowest of all with 15% of respondents.

Smart grids are expected to lead to the emergence of new actors in the market, such as aggregators and electricity service providers among others [42]. The results, however, show that the remaining three actors were selected by small shares of respondents from the stakeholder groups, ranging between 0 and 15%. Some respondents expressed that “technology suppliers” that provide the technical solutions can offer new business models for end-users to invest in active buildings whereas others argue that “third-party suppliers” may also play a role by financing the investments. Such business models, however, would involve sharing the economic benefits of smart grids, as pointed out by one of the respondents: *“If you hire a company to reduce your energy use, it is hard to get your money back or payback in short time if you are a resident. It can take several years, or up to 20 years to have it paid back.”*ED4.

The results suggest that electricity retail companies are not considered a prominent actor to invest in active buildings. Eight respondents selected the answer “Other” and provided their answers in the form of free-text. Three of the respondents indicated that the state should undertake the investments whereas two respondents expressed that there should be subsidies for the development of active buildings. There was one respondent who answered fibre operators, while another answered that active buildings should be financed by governmental organisations, such as the Swedish Energy Agency. Finally, a respondent answered that energy companies should undertake the investments, but did not specify a certain actor.

5. Conclusions

In this study, key stakeholders from the Swedish energy and buildings sectors answered semi-structured interviews and a web survey to present their views on the active building concept, smart grid features in buildings, barriers to their development and the actors to invest in active buildings. The findings show that the active building concept, according to the energy and buildings sectors, refers to buildings that assist in the operation of electricity networks by energy demand flexibility. According to the two sectors, active buildings support demand response but do not necessarily involve self-generation of electricity. In fact, the features that target flexible energy demand in buildings are regarded as the most important by the stakeholder groups.

The most significant barriers to the development of active buildings in Sweden, according to the energy and buildings sectors, are financial. The low electricity prices in the country combined with high costs of some technologies, such as automation systems and smart home appliances, create weak incentives for investments due to the perceived high economical risks. Accordingly, business models that reduce the financial burdens and risks of investments can play a key role in the development, especially given that building owners and housing companies, which may not have access to large amounts of funds, are the perceived actors by the stakeholders to invest in active buildings.

Based on the findings of this study, it is possible to make several recommendations. Granting consumers free of charge access to hourly electricity consumption data, as proposed by the Swedish Coordination Council for Smart Grid, could influence the energy behaviour of consumers effectively if combined with hourly electricity price data and personalised energy advices. Such information can be communicated to consumers via mobile apps and in-home displays, of which the latter can be supplied collaboratively by the energy and buildings sectors. The results show that construction companies are especially positive towards user response to electricity prices and GHG emissions, which may act as a departure point for building inter-sectoral collaboration. The diffusion of technologies with lower costs, e.g., displays and energy advice systems, can pave the way for more advanced active building technologies, such as smart appliances and home automation systems which involve larger investments and higher economic risks. This, however, would require the revision of the current regulations to allow more dynamic electricity distribution tariffs, which not only would create stronger incentives for demand response but would also lead to new business models that target the development of active buildings. In the process, dialogue and cooperation between the energy and buildings sector would be instrumental for the wider diffusion of the technologies.

Acknowledgements

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Appendix A. –List of respondents that were quoted in the text

	Source	Stakeholder group	Ownership	Position	Additional information
ED1	Interview	Electricitydistribution	State owned	Development manager	71.9 TWh/year delivered electricity
ED2	Interview	Electricitydistribution	Privately owned	Project manager	38 TWh/year delivered electricity
ED3	Interview	Electricitydistribution	Privately owned	Project manager	14.1 TWh/year delivered electricity
ED4	Interview	Electricitydistribution	Municipally owned	Market manager	1.75 TWh/year delivered electricity
DH1	Interview	District heating	Municipally owned	Environmental manager	0.96 TWh/year delivered heat
DH2	Survey	District heating	Municipally owned	Department manager	0.13 TWh/year delivered heat
DH3	Interview	District heating	Municipally owned	Business manager	0.68 TWh/year delivered heat
DH4	Survey	District heating	Municipally owned	Chief executive officer	0.10 TWh/year delivered heat
ER1	Interview	Electricity retail	State owned	Business developer	42 TWh/year sold electricity
C1	Interview	Construction	Privately owned	Energy strategist	13 000 total number of employees
C2	Interview	Construction	Privately owned	Technical manager	57 000 total number of employees
H1	Survey	Housing	Municipally owned	Chief executive officer	12 total number of employees
H2	Interview	Housing	Municipally owned	Technical manager	406 total number of employees
H3	Interview	Housing	Municipally owned	Environmental manager	360 total number of employees

Appendix B. –List of interviewees

	Stakeholder group	Ownership	Position	Additional information
1	Electricitydistribution	Municipally owned	Market manager	1.75 TWh/year delivered electricity
2	Electricitydistribution	Privately owned	Project manager	38 TWh/year delivered electricity
3	Electricitydistribution	State owned	Development manager	71.9 TWh/year delivered electricity
4	Electricitydistribution	Privately owned	Project manager	14.1 TWh/year delivered electricity
5	Electricity retail	State owned	Business developer	42 TWh/year sold electricity
6	Electricity retail	Municipally owned	Market manager	0.48 TWh/year sold electricity
7	District heating	Municipally owned	Business manager	1.5 TWh/year delivered heat
8	District heating	Municipally owned	Environmental manager	0.96 TWh/year delivered heat
9	District heating	Municipally owned	Business manager	0.68 TWh/year delivered heat
10	Construction	Privately owned	Technical manager	57 000 total number of employees
11	Construction	Privately owned	Energy manager	2200 total number of employees
12	Construction	Privately owned	Energy strategist	13 000 total number of employees
13	Housing	Municipally owned	Environmental manager	360 total number of employees
14	Housing	Cooperative company	Sustainability manager	2300 total number of employees
15	Housing	Municipally owned	Technical manager	115 total number of employees
16	Housing	Municipally owned	Technical manager	406 total number of employees

Appendix C. –List of interview questions

1. Would you like to be anonymous?
2. What do you think of when you hear the words "active building"?
3. What are the factors that negatively impact the development of active buildings?
4. Can you please grade the following smart grid features in buildings based on their importance?
- *Self-generation of electricity*
  ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Important
- *Local energy storage*
  ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Important
- *User response to electricity prices*
  ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Important
- *User response to GHG emissions*
  ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Important
- *Electric vehicles*
  ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Important
- *Home automation*
  ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Important
- *Smart electrical appliances*
  ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Important
- *Visualisation of energy use*
  ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 – Important

- *Smart systems that assist in energy-related decisions*
  ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 – Important
- *Hourly metering of electricity*
  ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 – Important

5. Who do you think will undertake the investments for the infrastructure?
6. Do you expect collaborations between sectors or the emergence of new actors for the investments?
7. Do you think that the wider use of active building technologies will significantly change the energy market conditions and business models in the future?
- (Yes) In what ways do you think that it will change?
8. Do you think that the regulatory framework in Sweden is suitable for the development of active buildings?
9. Do you think that end-users are ready for the changes that smart grids will bring? If not, what do you see as useful to change this condition?

Appendix D. —List of survey questions

1. Which of the following comes to your mind when you hear the words "active building"?
You can make multiple selections or specify a feature that is not listed by selecting "Other" and answering the next question.

- Interaction with the energy system
- Environmentally friendliness
- Automation of energy activities
- Local energy storage
- User response to emissions
- User response to electricity prices
- Self-generation
- Flexible electricity use
- Don't know
- Other

2. Please specify the feature or features that come to your mind when you hear the words "active building" but are not included in the list.[1]
3. An active building participates in the efficient operation of the electricity network by energy demand flexibility, small-scale power production and storage.
   It provides real-time information about energy prices and related emissions as well as functions that allow manual or automatic energy management.
   Please continue the survey by clicking on the arrow below.
4. How would you rate the importance of the following features for buildings to become more 'active' in the energy system?
Please select your answer on a scale from 1 to 5, with 1 meaning the lowest importance and 5 meaning the highest importance.

- *Self-generation of electricity*

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know
- *Local energy storage*

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know
- *User response to electricity prices*

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know
- *User response to GHG emissions*

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know
- *Electric vehicles for energy storage*

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know
- *Automation of energy activities*

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know
- *Visualisation of energy use*

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know
- *Smart systems that assist in energy-related decisions*

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know

5. Which of the following factors do you think that negatively impact the development of 'active buildings' in Sweden?

- Lack of suitable business models
- Insufficient inter-sectoral cooperation
- High uncertainties, e.g. economic risks
- Undeveloped technologies
- Lack of standardisation of technologies
- Regulatory framework

- Lack of interest
- Lack of initiatives
- High investment costs
- Low energy prices
- Don't know
- Other (Please specify in the next question)

6. Please specify the factors that negatively impact the development of "active buildings" in Sweden but are not included in the list.[2]
7. Who do you think should invest in the infrastructure that supports active buildings?

Please select one of the following actors or specify an actor that is not included in the list by selecting "Other" and answering the next question.

- Building owner/housing company
- Electricity retail companies
- Third party suppliers
- Technology suppliers
- Electricity distribution companies
- Don't know
- Other

8. Please specify the actors you think that should invest in the infrastructure that supports active buildings but are not included in the list.[3]

[1]Only the respondents that selected "Other" were asked this question.
[2,3]Only the respondents that selected "Other" were asked this question.

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