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Stakeholders’ perspectives on Energy Flexible Buildings

Energy in Buildings and Communities Programme Annex 67 Energy Flexible Buildings

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International Energy Agency

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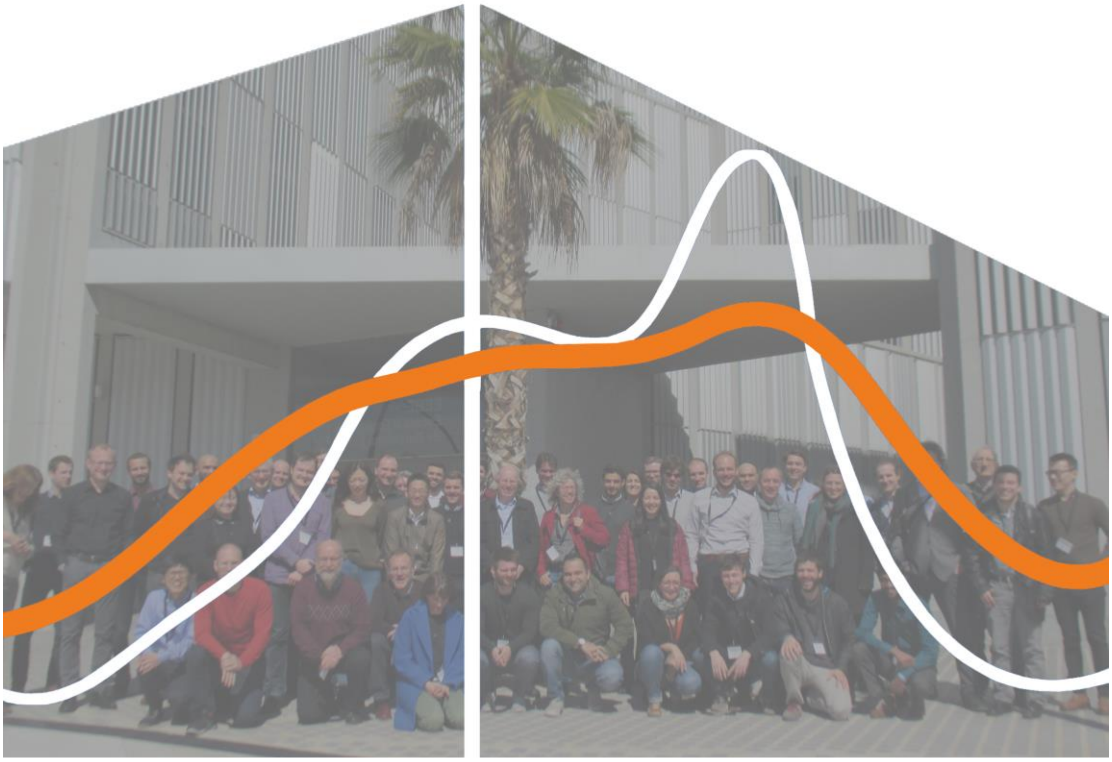

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International Energy Agency

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Annex 67 Energy Flexible Buildings

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 28 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates research and development in a number of areas related to energy. The mission of the Energy in Buildings and Communities (EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the IEA-EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)

The research and development strategies of the IEA-EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. The research and development (R&D) strategies of IEA-EBC aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five focus areas for R&D activities:

- Integrated planning and building design
- Building energy systems
- Building envelope
- Community scale methods
- Real building energy use

The Executive Committee

Overall control of the IEA-EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA-EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA-EBC Executive Committee, with completed projects identified by (*) and joint projects with the IEA Solar Heating and Cooling Technology Collaboration Programme by (☼):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)

Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: ☼ Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: ☼ Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: ☼ Towards Net Zero Energy Solar Buildings
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods (*)
Annex 54: Integration of Micro-Generation & Related Energy Technologies in Buildings
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy & CO_2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy & CO_2 Emissions for Building Construction (*)
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling & Low Temperature Heating in Buildings (*)
Annex 60: New Generation Computational Tools for Building & Community Energy Systems (*)
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (*)
Annex 62: Ventilative Cooling (*)
Annex 63: Implementation of Energy Strategies in Communities (*)
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Energy Principles (*)
Annex 65: Long-Term Performance of Super-Insulation in Building Components and Systems (*)
Annex 66: Definition and Simulation of Occupant Behaviour in Buildings
Annex 67: Energy Flexible Buildings

Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings
Annex 70: Building Energy Epidemiology: Analysis of Real Building Energy Use at ScaleAnnex 71: Building Energy Performance Assessment Based on In-situ Measurements
Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings
Annex 73: Towards Net Zero Energy Public Communities
Annex 74: Energy Endeavour
Annex 75: Cost-effective Strategies to Combine Energy Efficiency Measures and Renewable Energy Use in Building Renovation at District Level
Annex 76: ☼ Deep Renovation of Historic Buildings towards Lowest Possible Energy Demand and CO_2 Emissions
Annex 77: ☼ Integrated Solutions for Daylight and Electric Lighting
Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications
Annex 79: Occupant-Centric Building Design and Operation
Annex 80: Resilient Cooling
Annex 81: Data-Driven Smart Buildings

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
Working Group - HVAC Energy Calculation Methodologies for Non-residential Buildings
Working Group - Cities and Communities
Working Group - Building Energy Codes
Working Group - International Building Materials Database

Management summary

Stakeholder acceptance and behaviour are crucial to the success of strategies for energy flexibility in buildings. Without careful design and implementation, introducing energy flexibility has the potential to disrupt occupant lifestyles, building systems for thermal comfort and health, as well as potentially increasing cost or energy consumption. Stakeholder acceptance and behaviour may also be a barrier, but this can be reduced, or overcome entirely, if the related stakeholders are informed about flexibility measures and support any measures that are introduced. Stakeholder acceptance and behaviour is, therefore, an important source of knowledge for the Annex 67 project as some solutions, although technically sound, may not be feasible as the consequences for the involved stakeholders may not be acceptable to them.

There is a wide range of different stakeholders who may be affected by energy flexibility measures: end-users (occupants of buildings), building owners, facility managers, Energy Service Companies (ESCOs), developers, architects, contractors, and product/system suppliers. The energy flexibility is ultimately useful for aggregators, DSOs (Distribution System Operators), TSOs (Transmission System Operators), and district heating suppliers. It is important to establish a comprehensive understanding of acceptance, behaviour, and motivation at different levels of involvement for the relevant stakeholders.

Buildings can have an important role in energy flexibility due to their potential flexible energy consumption and distributed energy resources. Different types of building (residential, commercial, and industrial) can provide different energy flexibility, not only due to their energy profiles and DR opportunities, but also according to their potential for adopting energy and monitoring technology or HVAC (Heating, ventilation, and air conditioning) service solutions. The latter can be highly influenced by building and asset management strategies, for example timelines foreseen for maintenance or renovation of buildings. In this respect, there currently seems more potential for business opportunities related to commercial and industrial buildings with high energy consumption than, for example, for residential buildings with low energy consumption.

The flexibility resources and potentials are different for different types of buildings and building as-set managers have different needs and behaviours compared to building owners, end users, electricity and heat providing stakeholders. Thus, it is essential to understand stakeholders' needs and behaviour, not only regarding comfort and energy requirements, but also regarding their possible position within business models, in order to be able to develop feasible market access strategies for different types of actors. Meanwhile, incentive programs, national regulations, local policies, and energy and construction market characteristics are important to the stakeholders' activation for continuing the development of business ideas. Four business model for buildings' participation in the aggregation market have been proposed and are discussed in chapter 11 (shown in Table 11.1).

The roles, motivations, and barriers for different stakeholders in energy flexible buildings have been discussed in the sixteen cases presented in this report (shown in Table 1). Based on the sixteen cases, the opportunities and barriers for energy flexible buildings have been investigated and divided into five dimensions (shown in Table 11.2).

By systematically studying the motivations and barriers for energy flexibility in buildings, recommendations for how to strengthen the motivations and how to eliminate or reduce the barriers have been developed. The recommendations for related stakeholders are presented in chapter 11 (shown in Table 11.3).

It is found that, although ‘consumer driven/centred’ approaches have been emphasized in recent years, policy makers are still the lead stakeholders for strengthening opportunities and eliminating barriers in the energy system. To establish and realize the markets for energy flexible buildings, decentralization of the power hierarchy is necessary, especially for international collaboration and trading.

This deliverable is organized as eight chapters presenting the sixteen study cases (shown in Table 1). The Introduction summarizes the stakeholder roles, motivations, and barriers discussed in Annex 67, and the methodologies applied in each case. The Recommendation chapter discusses business ideas for energy flexible buildings in both the electricity and heating markets including policy recommendations. Chapters 3-10 with case studies are structured to include an introduction, backgrounds, cases (including methodology, results and discussion), and a conclusion. In total, thirteen authors have contributed to different parts of the report (shown in Table 2).

Table 1 List of chapters related to study cases.

Chapter	Title	Building or energy type	Cases
Chapter 3	Building Managers	Campus buildings	Building managers in energy flexible campus buildings
		Retail buildings	Building manager in energy flexible retail buildings
Chapter 4	Occupants	Households	Households' energy flexibility in in the Netherlands
		Office buildings	Large-scale Italian survey for energy flexibility in office buildings
		Campus buildings	Occupants in energy flexible campus buildings
Chapter 5	Energy suppliers	District heating	Demand response (DR) opportunities and challenges for district heating suppliers in Denmark Stakeholder's perception and motivation on smart district heating grids using energy flexible buildings
Chapter 6	Aggregators	N/A	Aggregators in the future Danish and Austrian electricity market
Chapter 7	Technology providers	N/A	Test of model predictive control (MPC) technology prototype
Chapter 8	Building energy analytics and consulting	N/A	Energy consultancy in the Danish energy flexible buildings The role of energy analytics in the energy flexible buildings
Chapter 9	The National Regulatory Authority	N/A	The National Regulatory Authority in the Danish and Austrian energy market
Chapter 10	Industrial consumers	Greenhouses Brewery	Business opportunities for Building-to-Grid
		Cooling Factory	Industrial consumers' acceptance of smart grid solutions

Table 2 Authors of the report.

Chapter Title	Participants	University
Chapter 2 - Report introduction	Zheng Ma	University of Southern Denmark
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Chapter 3 – Building Managers	Zheng Ma	University of Southern Denmark
Chapter 4 – Occupants	Rongling Li	DTU
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	Ilaria Vigna	EURAC research
	Zheng Ma	University of Southern Denmark
Chapter 5 – Energy suppliers	Tao Ma	Shanghai JiaoTong University
	Armin Knotzer	AEE- Institute for Sustainable Technologies
	Steffen Petersen	Aarhus University
	Rasmus Elbæk Hedegaard	Aarhus University
Chapter 6 – Aggregators	Mette Jessen Schultz	University of Southern Denmark
Chapter 7 – Technology providers	Theis Heidmann Pedersen	Aarhus University
	Steffen Petersen	Aarhus University
	Rasmus Elbæk Hedegaard	Aarhus University
Chapter 8 – Building energy analytics and consulting	Mette Jessen Schultz	University of Southern Denmark
Chapter 9 – The National Regulatory Authority	Mette Jessen Schultz	University of Southern Denmark
Chapter 10 – Industrial consumers	Jonas Korsgaard	University of Southern Denmark
Chapter 11 – Recommendation	Zheng Ma	University of Southern Denmark
	Jim Parker	Leeds Beckett University
	Erwin Mlecnik	TU Delft

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Abbreviations

Abbreviations	Meaning
AVA	Affald Varme Aarhus
BAS	Building automation systems
BEMS	Building Energy Management Systems
BRP	Balance responsible party
CAQDAS	Computer-assisted qualitative data analysis software
CHP	Combined heat and power
CSR	Corporate Social responsibility
DER	Distributed energy resource
DH	Thermal transmittance of a building element
DR	Demand Response
DRM	Demand Response Management
DSM	Demand side management
DSO	Distribution system operator
EE	Energy Efficiency
E-MPC	Economic Model Predictive Control
EM	Energy Management
EMS	Energy management system
EPEX	European Power Exchange
EU	European union
ESCO	Energy Service Company
GHG	Greenhouse gas
HVAC	Heating, ventilation, and air conditioning
IAQ	Indoor air quality
ICT	Information and communication technology
LCOE	Levelized cost of electricity
LED	Light-emitting diode
MPC	Model predictive control
NGO	Non-Governmental Organization
NZEB	Nearly Zero Energy Buildings
NRA	National Regulatory Authority
PID	Proportional–integral–derivative
PSO	Public Service Obligations
PV	Photovoltaics
QoS	Quality of service
RE	Renewable Energy
RES	Renewable Energy Systems
ROI	Return on Investment
STD	District heating

Abbreviations	Meaning
TSO	Transmission system operator
VFD	Variable frequency drive
VPP	Virtual Power Plant

1. Introduction to IEA EBC Annex 67

Substantial and unprecedented reductions in carbon emissions are required if the worst effects of climate change are to be avoided. A major paradigmatic shift is, therefore, needed in the way heat and electricity are generated and consumed in general, and in the case of buildings and communities in particular. The reduction in carbon emissions can be achieved by firstly: reducing the energy demand as a result of energy efficiency improvements and secondly: covering the remaining energy demand by renewable energy sources. Applying flexibility to the energy consumption is just as important as energy efficiency improvements. Energy flexibility is necessary due to the large-scale integration of central as well as decentralized energy conversion systems based on renewable primary energy resources, which is a key component of the national and international roadmaps to a transition towards sustainable energy systems where the reduction of fuel poverty and CO2-equivalent emissions are top priorities.

In many countries, the share of renewable energy sources (RES) is increasing parallel with an extensive electrification of demands, where the replacement of traditional cars with electrical vehicles or the displacement of fossil fuel heating systems, such as gas or oil boilers, with energy efficient heat pumps, are common examples. These changes, on both the demand and supply sides, impose new challenges to the management of energy systems, such as the variability and limited control of energy supply from renewables or the increasing load variations over the day. The electrification of the energy systems also threatens to exceed already strained limits in peak demand.

A paradigm shift is, thus, required away from existing systems, where energy supply always follows demand, to a system where the demand side considers available supply. Taking this into consideration, flexible energy systems should play an important part in the holistic solution. Flexible energy systems overcome the traditional centralized production, transport and distribution-oriented approach, by integrating decentralized storage and demand response into the energy market. In this context, strategies to ensure the security and reliability of energy supply involve simultaneous coordination of distributed energy resources (DERs), energy storage and flexible schedulable loads connected to smart distribution networks (electrical as well as thermal grids).

Looking further into the future, the ambition towards net zero energy buildings (NZEB) imposes new challenges as buildings not only consume, but also generate heat and power locally. Such buildings are commonly called prosumers, which are able to share excess power and heat with other consumers in the nearby energy networks. Consequently, the energy networks must consider the demand of both heat and electricity as well as the local energy generation. If not, it may result in limitations of the amount of exported energy for building owners to avoid power quality problems; for example, Germany has already enforced restrictions on private PV generation exported to the grid. Furthermore, today the distribution grid is often sized based on buildings that are heated by sources other than electricity. However, the transition to a renewable energy system will, in many areas, lead to an increase in electrical heating, by heat pumps for example, which will lead to an increase in the electricity demand even if the foreseen reduction in the space heating demand via energy renovation is realized. The expected penetration of electrical vehicles will increase the loads in the distribution grids, but they may also be used for load shifting by using their batteries; they could in effect become mobile storage systems. All these factors will, in most distribution grids, call for major reinforcement of the existing grids or for a more intelligent way of consuming electricity in order to avoid congestion problems. The latter approach is holistically referred to as a 'Smart Grid' (or as a Smart Energy Network, when energy carriers other than electricity are considered as well) where both demand and local production are controlled to stabilize the energy networks and thereby lead to a better exploitation of the available renewable energy sources towards a decarbonisation of the building stock. Buildings are, therefore, expected to have a pivotal role in the development of future Smart Grids/Energy networks, by providing Energy Flexibility services.

As buildings account for approximately 40 % of the annual energy use worldwide, they will need to play a significant role in providing a safe and efficient operation of the future energy system. They have the potential to offer significant flexibility services to the energy systems by intelligent control of their thermal and electric energy loads. More specifically, a large part of the buildings' energy demand may be shifted in time and may thus significantly contribute to increasing flexibility of the demand in the energy system. In particular, the thermal part of the energy demand, e.g. space heating/cooling, ventilation, domestic hot water, but also in some cases hot water for washing machines, dishwashers and heat to tumble dryers, can be shifted. Additionally, the demand from other de-vices like electrical vehicles or pool pumps, can also be controlled to provide energy flexibility.

All buildings have thermal mass embedded in their construction elements, which makes it possible to store a certain amount of heat and thereby postpone heating or cooling from periods with low RES in the networks to periods with excess RES in the networks without jeopardizing the thermal comfort. The amount of thermal storage available and how quickly it can be charged and discharged affect how this thermal storage can be used to offer flexibility. Additionally, many buildings may also contain different kinds of discrete storage (e.g. water tanks and storage heaters) that can potentially contribute to the Energy Flexibility of the buildings. A simple example of a discrete storage system is the domestic hot water tank, which can be pre-heated before a fall in available power. From these examples, it is evident that the type and amount of flexibility that can be offered will vary among buildings. A key challenge is, therefore, to establish a uniform frame-work that describes how flexibility can be offered in terms of quantity and quality.

Storage are often necessary in order to obtain Energy Flexibility. However, storage have losses, which may lead to a decrease in the energy efficiency in the single building. But as Energy Flexibility ensures a higher utilization of the installed RES, the efficiency of the overall energy system will increase. A decrease in efficiency will mainly be seen in well-controlled buildings, however, most buildings are not well-controlled. In the latter case, the introduction of Energy Flexibility may typically lead to a more optimal control of the buildings and in this way simultaneously increase the energy efficiency of the buildings.

Various investigations of buildings in the Smart Grid context have been carried out to date. However, research on how Energy Flexibility in buildings can actively participate the future energy system and local energy communities, and thereby facilitate large penetration of renewable energy sources and the increasing electrification of demand, is still in its early stages. The investigations have either focused on how to control a single component - often simple on/off controlled - or have focused on simulations for defining indicators for Energy Flexibility, rather than on how to optimize the Energy Flexibility of the buildings themselves.

The concept of flexible loads, demand side management and peak shaving is of course not new, as demand response already in the 1970s was utilized in some power grids. Although the concept is not new, before now there was no overview or insight into how much Energy Flexibility different types of building and their usage may be able to offer to the future energy systems. This was the main, although not sole, reason why IEA EBC Annex 67 Energy Flexible Buildings was initiated.

1.1 IEA EBC Annex 67

The aim of IEA EBC Annex 67 was to increase the knowledge, identify critical aspects and possible solutions concerning the Energy Flexibility that buildings can provide, plus the means to exploit and control this flexibility. In addition to these technical aims, Annex 67 also sought to understand all stakeholder perspectives - from users to utilities - on Energy Flexibility, as these are a potential barrier to success. This knowledge is crucial for ensuring that the Energy Flexibility of buildings is incorporated into future Smart Energy systems, and thereby facilitating the transition towards a fossil free energy system. The obtained knowledge is also important when developing business cases that will utilize building Energy Flexibility in future energy systems – considering that utilization of Energy Flexibility in buildings may reduce costly upgrades of distribution grids.

The work of IEA EBC Annex 67 was divided into three main areas:

- terminology and characterization of Energy Flexibility in buildings
- determination of the available Energy Flexibility of devices, buildings and clusters of buildings
- demonstration of and stakeholder’s perspective on Energy Flexible buildings

1.1.1. Terminology for and characterization of energy flexibility in buildings

A common terminology is important in order to communicate a building’s or a cluster of buildings’ ability to provide Energy Flexible services to the grid. The available Energy

Flexibility is often de-fined by a set of generally static Key Performance Indicators. However, the useful Energy Flexibility will be influenced by internal factors such as the form or function of a building, and external factors, such as local climatic conditions and the composition and capacity of the local energy grids. There is, therefore, a need for a dynamic approach in order to understand the services a building can provide to a specific energy grid. A methodology for such a dynamic approach has been developed during the course of IEA EBC Annex 67.

The findings in the area of terminology and characterization of Energy Flexibility in buildings are reported in the deliverable “Characterization of Energy Flexibility in Buildings” mentioned below.

1.1.2. Determination of the available energy flexibility of devices, buildings and clusters of buildings

Simulation is a powerful tool when investigating the possible Energy Flexibility in buildings. In IEA EBC Annex 67, different simulation tools have been applied on different building types and Common Exercises have been carried out on well-defined case studies. This approach increased the common understanding of Energy Flexibility in buildings and was useful for the development of a common terminology.

Simulations are very effective to quickly test different control strategies, among which some may be more realistic than others. Control strategies and the combination of components were, there-fore, also tested in test facilities under controllable, yet realistic, conditions. Hardware-in-the-loop concepts were utilized at several test facilities, where, for example, a heat pump and other components were tested combined with the energy demand of virtual buildings and exposed to virtual weather and grid conditions.

The results of the investigations are described in several of the below mentioned publications by IEA EBC Annex 67.

1.1.3. Demonstration of stakeholders perspective on energy flexible buildings

In order to be able to convince policy makers, energy utilities and grid operators, aggregators, the building industry and consumers about the benefits of buildings offering Energy Flexibility to the future energy systems, proof of concept based on demonstrations in real buildings is crucial. Ex-ample cases of obtaining Energy Flexibility in real buildings have, therefore, been investigated and reported in reports, articles and papers and as examples in the deliverables of IEA EBC Annex 67.

When utilizing the Energy Flexibility in buildings, the comfort, economy and normal operations of the buildings can be influenced. If the owner, facility manager and/or users of a building are not interested in exploiting energy flexibility to gain financial benefit by increasing building smartness, it does not matter how high energy flexible potential the building has, as the building will not be an asset for the local energy infrastructure. However, the involvement of utilities, regulators and other stakeholders, can provide financial and regulatory incentives and increase awareness of and thereby participation in providing Energy Flexibility. It is, therefore, very important to understand which barriers exist for the stakeholders involved in the Energy Flexible buildings and how they may be motivated to contribute with Energy Flexibility in buildings to stabilize the future energy grids. Investigating the barriers and benefits for stakeholders is, therefore, of paramount importance and work was completed in IEA EBC Annex 67 to understand these in more detail. Findings from this work are described in the report “Stakeholder perspectives on Energy Flexible Buildings” mentioned below.

1.1.4. Deliverables from IEA EBC Annex 67

Many reports, articles and conference papers have been published by IEA EBC Annex 67. participants. These can be found on annex67.org/Publications/Deliverables.

The main publications by IEA EBC Annex 67 are, however, the following reports, which all may be found on annex67.org/Publications/Deliverables.

Principles of Energy Flexible Buildings summarizes the main findings of Annex 67 and targets all interested in what Energy Flexibility in buildings is, how it can be controlled, and which services it may provide.

Characterization of Energy Flexibility in Buildings presents the terminology around Energy Flexibility, the indicators used to evaluate the flexibility potential and how to characterize and label Energy Flexibility.

Stakeholder’ perspectives on Energy Flexible buildings displays the view point of different types of stakeholders towards Energy Flexible Buildings.

Control strategies and algorithms for obtaining Energy Flexibility in buildings reviews and gives examples on control strategies for Energy Flexibility in buildings.

Experimental facilities and methods for assessing Energy Flexibility in buildings describes several test facilities including experiments related to Energy Flexibility and draws recommendations for future testing activities.

Examples of Energy Flexibility in buildings summarizes different examples on how to obtain Energy Flexible Buildings.

Project Summary Report brief summary of the outcome of Annex 67.

2. Report Introduction

Stakeholder acceptance and behaviour are crucial to the success of strategies for energy flexibility in buildings. Without careful design and implementation, introducing energy flexibility has the potential to disrupt occupant lifestyles, building systems for thermal comfort and health, as well as potentially increasing cost or energy consumption. Stakeholder acceptance and behaviour may also be a barrier, but this can be reduced, or overcome entirely, if the related stakeholders are informed about flexibility measures and support any measures that are introduced. Stakeholder acceptance and behaviour is, therefore, an important source of knowledge for the Annex 67 project as some solutions, although technically sound, may not be feasible as the consequences for the involved stakeholders may not be acceptable to them.

There are a wide range of different stakeholders who may be affected by energy flexibility measures: end-users (occupants of buildings), building owners, facility managers, Energy Service Companies (ESCOs), developers, architects, contractors, and product/system suppliers. The energy flexibility is ultimately useful for aggregators, DSOs (District System Operators both power grids and district heating systems) and TSOs (Transmission System Operators) to balance supply and demand. In total, nine types of stakeholders with six types of buildings are presented and discussed in this report. Each chapter discusses a specific stakeholder, their roles, motivations, and potential barriers to energy flexible buildings. A summary of stakeholders' definitions, business function in buildings, and roles in energy flexible buildings is collected in Table 2.1, and their motivations and barriers for all case studies are listed in Table 2.2.

It is important to establish a comprehensive understanding of acceptance, behaviour, and motivation at different levels of involvement for the relevant stakeholders. Various methodologies, including questionnaires and interviews, have been carried out. These are all listed in Table 2.3.

Table 2.1 A summary of stakeholders' definitions, business function in buildings, and roles in energy flexible buildings.

Stakeholders	Definition/note	(Building) Business function	Roles in energy flexible buildings
Energy managers in Campus buildings	Responsible for supervising the buildings' security, maintenance and repair in accordance with environmental and safety standards.	Campus buildings provide offices, classrooms, and other space types for education and research purposes.	The role of an Energy Manager (EM) involves facilitating energy conservation by identifying and implementing various options for saving energy, leading awareness programs, and monitoring energy consumption.
Energy managers in Retail buildings		Commercial supermarket type buildings selling a variety of products, which are owned or operated by the retailers.	
Building managers	Real estate building managers are responsible for the	Buildings are considered as assets in operation within	Building managers are close to (specific types of) users, they can also influence

	strategic management of entrusted buildings and surroundings from the viewpoint of the total life cycle and value chain.	neighbourhoods and energy networks.	strategy decisions and property developments and they can balance out the expectations and interests of investors and users within legal and marketing frameworks.
Households	A household consists of one or more people who live in the same dwelling	Residential buildings, e.g. single/multi-family home, condominium and, townhouse	End-users of energy in residential buildings.
Occupants in Office buildings	Employees, managers, interns, students, spend significant time seated at workspaces and at meeting rooms.	The main purpose of an office building is to provide a workplace and working environment primarily for administrative and managerial workers.	Consume energy for work related activities.
Occupants in Campus buildings	There are three types of occupants in the campus buildings: academics, students, and administration.	Occupants perform work and study activities in campus buildings.	Student occupants are the energy end-users, and they can provide feedback regarding the energy performance in campus buildings.
Electricity supplier	Electric utilities, system operators and local investors.	Invest in and operate the infrastructure for electricity generation and transmission.	Considers the interest of their stakeholders, the expected return of their investments and the balance of the grid.
District heating supplier	District heating suppliers are companies that mainly generate and distribute heat at the municipal level with often mixed cooperative, private and municipal ownership.	Suppliers interconnect single buildings by their energy networks, often forcing renewable energy. Invest in and operate the infrastructure for district heating generation and transmission.	District heat suppliers are managing energy in different ways (load, central or decentralized generation, and renewable energy). They are important players for the development of districts regarding energy systems. They consider the interest of their consumers and are often committed (obligated) to ensure high security of supply and reduce the environmental impact of the production.
Industrial consumers	Companies and activities involved in the process of producing goods for sale, especially in a factory or special area.	A building or structure in use, e.g. for the purposes of a trade carried on in a factory or other similar premises.	The single largest electricity consumer. Industrial consumers have heavy energy use and have already begun to implement smart grid technologies for production purposes.
Aggregators	The act of grouping distinct agents in a power system (i.e. consumers, producers, prosumers, or any mix thereof) to act as a single entity when engaging in the power system markets (both wholesale and retail) or selling services to the system operator(s)	All buildings.	The role of an Aggregator involves pooling energy units, switch energy consumption due to market condition, and control of each unit due to individual settings and optimization of the end-users' energy usages.

Building automation providers	Providing building automation technology (sensors, actuators, software, and communication infrastructure).	All buildings	Increases the potential for energy efficient/flexible operation of buildings.
Energy consulting	A sub-discipline of environmental consulting that focuses on optimizing a business' energy usage, as well as the sources from which the actual energy is derived.	All buildings.	Consultancy services, including energy analytics and conducting innovative projects with illumination and documentation.
Energy analytics	Interdisciplinary stakeholder focusing on designing and optimizing energy market and helping customers to understand and reduce energy consumption.	All buildings.	Investigate and analyse the market condition. Set up interdisciplinary scenarios of the energy sector to find the most efficient solution.
The National Regulatory Authority	Stakeholder that make sure that the energy market is competitive and that the customers are treated fairly.	All buildings.	Responsible for creating a fair market for all stakeholders. They aim to make the market transparent for the customers and ensure that the methods which are used for the settlement of energy prices are consistent with the laws in force.

Table 2.2 A summary of stakeholders’ motivations and barriers for energy flexible buildings.

Stakeholders	**The motivation for energy flexible buildings**	**Barriers to energy flexible buildings**
Energy managers in Campus buildings	Building automation and distributed energy resources create possibilities for buildings to provide energy flexibility to the grid and thereby gain a financial benefit.	Energy efficiency to be more important than providing flexibility to the grid; Many buildings are too old and need to be refurbished; The benefit of providing energy flexibility to the grid is not sufficient; Building management systems need to be either installed or upgraded to response to the demand from the grid.
Energy managers in Retail buildings	Ready to adopt the implicit demand response by manual energy control compared to the utility control or building automation: • The company goal influences the willingness of DR participation. • Related knowledge of energy flexibility influences the willingness of DR participation.	Significant concerns about: • Dynamic control can negatively influence the business operation • Dynamic control can negatively influence customer satisfaction (e.g. comfort) • Need to install new equipment or system • The company is Lacking knowledge • The ROI (Return on Investment) of installing the automatic control system
Building managers	Integrating opportunities for efficient use of renewable energy and heat sources and for reducing CO_2 emissions and primary energy use.	Detailed planning of technical changes in buildings and grids and data management strategies are needed, as well as development within changing policy frameworks within cost

		efficiency boundaries. Special attention is needed for creating social engagement in neighbourhoods and co-creation for innovation.
Households	The top three motivating factors for users adopting smart technologies were found to be: reduced energy bills (strongly motivating), financial rewards from the energy supplier (motivating), and seeing the effects of energy use actions (motivating).	More than 60 % of the respondents were unaware of smart grids. Multiple control options should be included in the development of smart technologies to achieve high user acceptance and therefore realize the energy flexibility of home appliances.
Occupiers in Office buildings	Economic savings, reduction in electricity consumptions and contribution in sustainability are most motivating factors to accept energy flexible usage in office buildings.	Concerns about smart control related to the possible risk of interference with work activities and with the privacy in office buildings.
Occupants in Campus buildings	‘University plans to become a green intelligent university’, ‘University tries to reduce the energy consumption’, ‘University tries to reduce the energy bill, and will put the saved bill into campus facility improvement’ can motivate students to accept the frequent indoor quality changes.	Student occupants believe the frequent changes in indoor comfort in classrooms can influence teaching and learning performance.
Electricity supplier	Reduce their need for new investments in the grid by load levelling and load shifting. Better control, better utilization of renewable energy and increased reliability of the grid.	Users lack knowledge and willingness to let their appliances and heating/cooling be shifted in smart-grids. There is a need for political incentives. The initial investment in smart meters and smart appliances will take time.
District heating supplier	Integrating the load management and opportunities for the use of renewable energy like biomass and solar thermal energy. So reducing CO_2 emissions and exploiting local energy sources. Optimize production and distribution of district heating, while mitigating the need to invest in untimely network upgrades.	Uncertainties related to technological costs, lack of knowledge, incentives, and regulation framework currently hinders the use of energy flexibility of buildings in district heating grids, more than concerns on data privacy or security issues. Demand response is still considered an unproven method. The relatively high complexity combined with the uncertain estimates of impact is a significant barrier. Furthermore, it is not clear how appropriate incentive mechanisms can be established.
Aggregators	The increase of fluctuating renewable energy resources creates the need to balance the system with DR. This creates the business opportunity for aggregators to provide customers in the built environment with a new services and opportunities for controlling their devices.	Fixed energy prices or prices with a very small variation which do not create an incentive for end-users to change their consumption habits. The market structure needs to be redesigned for aggregators to take part. New technology like blockchain is a competitor to the aggregator model.
Building automation providers	Additional functionality of their current product portfolio. Possibility for new markets, especially home automation.	No demand for energy flexibility functionality from society/consumers.
Energy consulting	Smart meters with two-way communication and half-hourly electricity pricing must be implemented to create an incitive for energy flexible buildings.	The complexity of the energy system regulation makes the energy system very difficult to be more flexible. The requirement for providing energy flexibility to the grid is high and complicated.

	Communication between energy suppliers and consumers is important.	Tariffs and taxes associated with power production are a large barrier to energy flexibility. Unclear schemes for buildings to provide energy flexibility: either everyday flexibility or emergency.
Energy analytics	More renewable energy in the system creates new opportunities for energy flexibility in buildings together with a rethink of the current energy system with a fixed tariff model and one-way communication.	Energy flexibilities access to the market. Regulation makes the system very complex, and service providers of energy flexibility need to be aware of all these regulation before entering the market. The incentive for providing energy flexibility in the building is low due to the relatively low savings it includes. The energy price is regulated by tariffs and taxes with needs to vary to reflect the market and grid situation. In reality, energy flexibility in buildings depends on a lot of stakeholders and other factors that need to be coordinated before it is a can be implemented in the market structure.
The National Regulatory Authority	Wants to create a fair and equal market for all stakeholders, which allows for more competition.	It is difficult for new stakeholders to enter the market, because stakeholders need to fulfil a lot of requirements.
Industrial consumers	Governmental incentives making energy flexibility more attractive; Some industrial consumers have installed distributed energy resources, it provides the opportunity of monetary gain for industrial consumers to participate in DR; Some industrial processes have the potential to provide energy flexibility, e.g. cooling; The desire to brand the company as “green”. It impacts the inscription stage but interconnects customer focus.	A high priority of service quality and process improvement; The concern of return on investment; Not familiar with DR solutions, and concern about the ease of use of the DR solutions; Do not actively seek involvement in DR activities. Some large industrial plants have their own capacity to generate heat and power by on-site CHP.

Table 2.3 Methodologies and stakeholders in studies cases.

Methodology	Types of stakeholders	Types of Buildings	Targeted countries
Case studies with interviews	Building managers	Campus buildings	Denmark
Questionnaire	Store managers	Retail buildings	Denmark and the Philippines
Questionnaire	Occupants	Campus buildings	Denmark
Interviews	Occupants	Campus buildings	Denmark
Questionnaire	Occupants	Office buildings	Italy
Questionnaire	Households	Residential buildings	Netherland
Case study	Electricity supplier	Residential buildings	Denmark
Questionnaire	District heating supplier	N/A	Austria

Methodology	Types of stakeholders	Types of Buildings	Targeted countries
Case studies with interviews	District heating supplier	N/A	Denmark
Interviews	Aggregators	N/A	Denmark
Experimental study	Building technology providers	Residential and commercial buildings	Denmark
Interviews	Energy consulting	N/A	Denmark and Austria
Interviews	The National Regulatory Authority	N/A	Denmark
Case studies with interviews	Industrial consumers	Industrial buildings	Denmark

3. Building Managers in Energy Flexible Buildings

3.1 Introduction

One important stakeholder in energy flexible buildings is the ‘building manager’ (or sometimes called the ‘energy manager’). Building/Energy managers usually exist in commercial buildings, for example, office buildings, retail buildings, or leisure buildings. However, the roles and responsibilities for the building/energy managers in the operation of energy flexible buildings are unclear, and the energy flexibility related activities vary based on the types of buildings.

Two case studies were conducted to investigate the participation of the building/energy managers and their opinions on energy flexibility. The first focuses on university campus buildings, the second is focused on retail buildings. The results from the case studies are summarized below:

Table 3.1 Summary of data collection and results.

Purpose	Type of Building	Methodology	Targeted aspect	Result highlight
Building managers’ activities and opinions	Campus buildings	Case study	Building management system Energy consumption Energy purchasing strategy	• Building managers believe that buildings can provide energy flexibility by building automation and distributed energy resources; • Building managers consider energy efficiency to be more important than providing flexibility to the grid. • The main barriers for buildings to provide energy flexibility are 1) many buildings are too old and need to be refurbished, 2) the benefit of providing energy flexibility to the grid is not sufficient, 3) building management systems need to be either installed or upgraded to response to the demand from the grid.
	Retail buildings	Questionnaire	Energy control Energy technology adoption Employees’ participation in an energy program Customers’ concern	• Retail stores are much readier to participate in the implicit demand response by manual energy control compared to the utility control or building automation. Meanwhile, store managers have significant concerns about business activities and indoor lighting compared to other aspects • The statistically significant influential factors for retail stores to participate in the demand response are related to whether the DR participation matches the company goal, influences business operation, and whether retail stores are lack of related knowledge • Retail stores believe that stakeholders should be informed about the DR activities but not involved in these activities • There are significant differences regarding the energy control preferences and concerns between retail stores in Denmark and the Philippines, but no significant difference regarding the stakeholder engagement

3.2 Background

In commercial buildings, Demand Response (DR) is commonly considered viable due to: 1) approximately one-third of commercial buildings being equipped with building automation systems (BAS) in many developed countries; 2) BAS already being integrated with the HVAC (Heating, ventilation, and air conditioning) control systems that can manipulate the control variables needed to provide regulation services; and 3) a large fraction of commercial buildings being equipped with fast-responding variable frequency drives (VFDs) (Hao et al., 2012). However, some owners/operators of commercial buildings are more reluctant to participate in DR due to the potential impact on their business routines and profits (Yang and Wang, 2016). For instance, hotels and hospitals operate 24/7, in general, reluctant to shift their usage of power due to consideration of their profits or occupants' comfort.

Therefore, the success of demand response is related to various aspects, for example, regulation, consumers' motivation, electricity suppliers' support, and it also depends on the collaboration of all the smart grid stakeholders (energinet.dk, 2011). The flexibility activation can require the establishment of agreements between different stakeholders. Building managers (sometimes called energy managers) are key stakeholders in energy flexible buildings. When considering the potential for energy flexibility in Denmark specifically, it is important to note existing market conditions. There is currently no energy flexibility market and there are also no incentives for buildings to provide energy flexibility. For example, the requirement for participating in the ancillary service market in Denmark is 1 MV. Most commercial buildings can, therefore, not participate in this market on an individual basis. Meanwhile, aggregators grouping consumption-side energy flexibility are not currently allowed to participate in the Danish energy market. There is usually a fixed electricity price for commercial buildings in Denmark that is based on negotiation with energy suppliers.

Building/store managers are responsible for supervising the buildings' security, maintenance and repair, in accordance with buildings' environmental and safety standards. On the other hand, store managers or energy management teams are responsible for energy management practices in retail stores and manage the retail store operation (Robert P. King, 2003). They usually collaborate with governments and other stakeholders regarding the monetary energy efficiency incentive programs (Carr, 2015). Energy managers in commercial buildings are usually assigned in the corporate department of large retail stores with the responsibility of developing effective energy management plans, evaluation and installation of energy management technologies, and negotiating with the utility partners regarding the electricity prices (Ochieng et al., 2014).

The majority of building managers are aware of the importance of energy saving and energy efficiency. The literature indicates that there are different drivers, barriers and benefits to the building managers regarding energy efficiency and flexibility. For instance, the barriers to energy flexibility implementation include financial, managerial and technological impacts.

3.2.1 Drivers to the energy flexibility implementation

Legislation and financial savings are the two main drivers for building managers regarding the implementation of energy flexible operations. Fiscal savings drivers vary between different building types. Typically, economical savings drive buildings that consume a large amount of electricity (e.g. grocery, food supermarket) to consider energy flexibility. Building managers often adopt energy-related technologies and flexibility resources (e.g. PVs or energy storage) due to energy legislation and building regulations. For instance, it has been shown that food supermarkets utilize efficient energy technologies because of rising energy costs and campaigns of Non-Governmental Organizations (NGO) to reduce Greenhouse gas (GHG) emissions (Ochieng et al., 2014).

Financial incentives provided by governments and utility companies also encourage building managers to utilize energy more efficiently. Although the electricity cost accounts for small percentages of the total operating cost, building managers are interested in any financial incentive that can help to increase profit (Connell et al., 2014). Moreover, demand response can drive energy flexibility and enhance the energy efficiency of commercial buildings, utilities, and grid operators. Recent research shows that demand response is considered as a secondary revenue stream for a supermarket chain as it lowers electricity cost (Connell et al., 2014) and lowers the wholesale energy market prices (Jianli et al., 2014). For instance, the demand response in the refrigeration system allows the adjustment of the demand for electricity (Connell et al., 2014).

Benefits and Barriers of the DR participation

The buildings' competence of energy flexibility to respond to the grid's demand, e.g. instability or price signal, can not only reduce energy cost, but could also receive compensation from the grid, and, potentially, improve collaboration with the energy suppliers.

Involvement in energy efficiency programs as part of a company's Corporate Social Responsibility (CSR), can help to improve the company's reputation (Ochieng et al., 2014). Research shows that flexible opening hours convey a positive image of retail stores (Kasulis and Lusch). The adoption of energy flexibility activities does not significantly influence the customers' shopping behaviour. An experiment in a large British supermarket indicated that customers did not notice changes in the indoor temperature during the experiment.

Not all building managers are convinced to adopt energy flexibility activities (Ochieng et al., 2014). Research published by Tassou et al. (Tassou et al., 2010) shows that building managers receive pressure to practice energy management because of energy legislation implemented by government. Moreover, the benefits and potential of energy flexibility show little Return on Investment (ROI). There is a lack of incentive for participation in energy flexibility initiatives from utilities providers or policy makers. Some utility incentives are not applicable to specific types of buildings. For example, food supermarkets sell more perishable products, and they have more energy flexibility resources, such as refrigeration, than stores that sell dry goods. Some incentives are classified on certain groups (e.g. motor replacement or one-for-one equipment change out incentives) (Carr, 2015).

3.3 Case 1 - building managers in energy flexible campus buildings

3.3.1 Introduction

This case study is based on a project conducted by the Center for Energy Informatics, University of Southern Denmark in 2017. The project aimed to investigate the motivation and barriers for energy flexibility in campus buildings. A conceptual framework of the readiness for energy flexible buildings was developed by conducting interviews with building automation suppliers, electricity supplier, district heating supplier, distribution system operator, energy service companies, experts in energy and buildings, building managers, and occupants.

This section introduces the building managers' roles and opinions in the energy flexible campus buildings; the original data source is described more comprehensively in (Ma and Jørgensen, 2018).

3.3.2 Methodology

The campus buildings selected in this case study include a range of architypes, including buildings of different age, with different building control systems and fabric. The case study buildings also provide a range of functions, including classrooms, offices and laboratories for example.

This project adopts the qualitative methodology of interviewing, to examine and report the experience of various stakeholders, and specifically their own reflection on energy flexible buildings. Qualitative research methodologies are commonly adopted when investigating new fields of study or when attempting to ascertain prominent issues (Corbin and Strauss, 2008). A case study in this project provides in-depth knowledge of the relationships between energy flexibility in buildings, building automation, and stakeholders' participation.

Two semi-structured, face-to-face interviews were conducted with service managers and staff in the service department of the University of Southern Denmark. The length of each interview with companies, building managers and experts was approximately one hour.

Table 3.2 Interview questions for Case-building managers in energy flexible campus buildings.

Category	Interview question
Role of building managers	What are your day-to-day responsibilities? How long have you been working in your current position? Where do you spend most of your time at the University?
Insulation	Which methods are used at the University for energy refurbishment? E.g. New windows, roof, additional insulation etc. Are there differences between the older and newer buildings? What are the pro/cons for the different solutions? Economical point of view, use of indoor space etc. and what is the future for insulation? New materials, new solutions etc.
Ventilation	Which kinds of ventilation solutions are used at the University? Are there any differences between the ventilation solutions in refurbished and new buildings? What are the consequences if the building does not have ventilation? What are the pro/cons of automated and manual ventilation solutions?
Indoor air quality	Under the construction and refurbishment of the University have you considered problems regarding air quality in the buildings? Are there differences between new and refurbished buildings? What are the solutions to keep the indoor air quality high? Do you measure the air quality at the University? How is it done and what is the air tested for? When is the air quality considered low?
Indoor control systems	Please explain the current control systems regarding lighting, temperature air-conditioning on campus Please talk about the degree of automation in currently installed systems on campus
Distribution resources	What distributed resources has the university installed? What agreement(s) are there for distributed resources? How have the distributed resources contributed to the university energy performance? Is there any future plan for adding distributed resources?
Energy flexibility	What are the current possibilities for participating in flexibility or demand response schemes? Any barriers to participation? Are the buildings at the University suited for a flexible energy system? Are there differences between the older and newer buildings? What do the buildings need to have to be a part of a flexible energy system? Do you have any plans regarding implementing of smart technology in the future?
Others	Are there any specific improvements in the indoor control systems you would highlight? Are there any specific technologies that you know which could contribute to these improvements? If the university has any specific energy conservation initiatives? Do energy conservation initiatives have an influence on indoor climate control systems? Which objective would have the highest priority – energy conservation or human comfort? What are the expected benefits from energy control systems compared to fully manual control system?

3.3.3 Results and discussion

Roles of building managers in campus buildings

The energy management of the campus buildings includes a variety of activities. In general, the energy management activities are divided into two-thirds of time for collection of consumption data, coordination with related energy database maintenance, and one-third of time on finding areas where improvements are possible. There are approximately 100 employees working with a variety of tasks with energy savings. For instance:

- Energy meter control, collection, and registration of water, electricity, and heat consumption
- Screening energy solutions for optimization and energy savings potential (ventilation, lighting, motors, toilets, faucets, etc.)
- Responsibility for energy spending
- Responsibility for temperature and air quality regulation
- Maintaining the energy consumption database
- Analyze photovoltaic cells
- Supervising contracts, bids and the process of construction
- Reporting to the Danish Energy Agency
- Building control systems

Existing systems and possible control system improvements

Building managers believe that buildings can provide energy flexibility by building automation and distributed energy resources. However, one of the barriers for campus buildings to provide energy flexibility is that building management systems need to be upgraded and to respond properly to activities in rooms and demand from the grid.

The building manager in the service department operates four different control systems (including ventilation control, temperature control, and lighting control) in the campus buildings, regulating different aspects of the energy systems. This increases the complexity of the operations, especially since there is no communication across different systems. The Campus buildings are publicly financed and must announce all system purchases for public tender; this, therefore, often leads to a diverse mix of systems that cannot be integrated and centrally controlled.

Ventilation control

In the selected case, there is central ventilation controlling multiple rooms in the campus buildings, and the building automation system decides whether the ventilation in a room should be opened based on the time schedule for room use. Some larger rooms, such as the auditorium, are served by individual ventilation systems. CO_2 is measured and used for control in these rooms. Each individual ventilation system services around 10 of the larger rooms and each of these has a physical valve that opens and closes depending on the CO_2 measurement in these rooms. The CO_2 level is an indicator of the number of people in the room and determines the ventilation operations. Air-conditioning is not used in the campus buildings, and, apart from the large rooms, the ventilation in most office rooms is only regulated based on temperature.

There are sensors that measure the indoor air quality (IAQ) with respect to the CO_2 level. For instance, "…the air quality is considered low when the CO_2 level is above 1000 ppm." stated the interviewed energy manager. It is necessary to check the IAQ in buildings, especially the IAQ problem in newer buildings with the increased insulation levels and air-tightness (Burroughs and Hansen, 2011). The ventilation system in newer buildings is adjusted to keep the CO_2 level below 1000 ppm. However, the ventilation system in the older buildings cannot be varied. These rooms are, therefore, ventilated by assuming the maximum amount of people in the rooms. This makes the ventilation less energy efficient. There are no mechanical ventilation systems in the very old campus buildings, they are only ventilated using natural ventilation.

In general, the difference between manual and automated ventilation is that manual ventilation either ventilates too much or too little, and, in theory, there is an optimal amount of ventilation and energy consumption optimized by automated ventilation (Zhou and Haghighat, 2009).

Temperature control

There is automatic temperature control in the campus buildings (e.g. public areas, classrooms, hallways, etc.). Radiators on campus are fitted with an actuator, which controls the temperature centrally. "A timer decides that from 8 am to 4 pm, the temperature is 21 °C, and in the remaining time, the temperature is lowered to about 19 °C" (stated by one service manager). There is a central control system of temperature in the newer buildings. A setpoint temperature for the whole building can be manually controlled in different classrooms by ±2 °C from the standard temperature. However, automatic control systems based on existing thermal management in public buildings are not very energy efficient (Li, 2012). Some rooms (e.g. offices/small rooms) are regulated by occupants directly via thermostats.

Lighting control

Lighting is usually controlled by movement sensors that turn off lights when rooms are not in use (Guo et al., 2010). Almost all buildings have manual lighting controls except in the newer buildings, which are controlled and adjusted automatically based on indoor light sensors.

In general, classroom management in campus buildings is good but not yet optimal. This may be due to the vastness of campus buildings and the differences in construction designs and ages. Compared to older buildings, newer buildings have more control measures installed to improve or maintain conditions and facilitate space management. This would explain the report of poor ventilation in older buildings and is further supported by the presence of standard protocols to respond to these reports of poor indoor conditions.

Energy control system improvement

The interviewed building managers believe that the implementation of building management systems can optimize buildings' energy efficiency, "the goal is to control as much as possible, heat, ventilation, and light, based on the needs of occupants" stated by the interviewed energy manager.

The current indoor climate control is handled through set-point regulation with limited manual input. The energy team aims to increase the automation of the regulation by incorporating predictive control mechanisms and would like to track inhabitants to minimize unnecessary regulation. This change in regulation scheme and control technology must be undertaken while managing a large network of relationships that should be satisfied.

For the improvement of heating and the indoor temperature, the main concern is to not heat too much when there are no people in the rooms. Therefore, many different sensors and systems are incorporated to make sure this does not happen. If the system can better communicate, the temperature could possibly be lowered further. More control according to use patterns can help, e.g. linking the booking system to the temperature control. For instance, in a newer building, the temperature is increased a few hours before a room is occupied, and the temperature set point is lower for the rest of the time. If it can be implemented and optimized in all rooms, temperatures could be lowered when rooms are not used, resulting in energy savings.

The main concern regarding ventilation is IAQ when rooms are not in use or only a few people are in a room. It is especially essential for older buildings. The energy team expects to have better documentation of building energy data in general in the future, especially for buildings that do not have sensors at the moment.

The current control schemes are linear control and have no prediction of occupant behaviour. The energy team intends to change this control scheme to be more predictive. This can be accomplished by using machine learning to predict occupant behaviour and take weather data into account when lighting, ventilation, and temperature must be controlled. The current control relies partly on direct user input, and the new scheme would rely on indirect user input via occupant tracking and more accurate CO_2 concentration measurements to determine how to regulate. In this context, the definition of a satisfactory comfort level becomes increasingly important.

Distributed Energy Resources and Energy Flexibility

The distributed energy resources on the campus are PVs with a yearly production of approximately 400,000 kWh. A PV system producing an additional 600,000 kWh is expected to be installed on the roof of the main campus building in 2019. This will further reduce the amount of electricity that is purchased from the main grid. The produced electricity is integrated into the campus grid because it would be more complicated to allocate it to a specific area, and it makes no difference due to the large size of the campus grid.

There is a wish to participate in demand response schemes. For instance, it has been considered to use the excess heat from the cooling of server rooms as a heat source for heat pumps to be used in the campus district heating system. However, there are barriers in the form of rigid billing methods and budgetary constraints which limit the possibilities for this energy saving solution. Meanwhile, the energy consumption is very fixed based on people's working schedule. Therefore, shifting consumption is not an option. Storage might create opportunity, but the investment might be too high without significant financial benefits.

Building refurbishment and investment for energy saving

Compared to providing energy flexibility to the grid, the main task for the building managers in the campus building is still energy efficiency, due to the national and international policies on energy efficiency and monetary benefit from the energy saving.

The potential energy savings are dependent on each buildings' age and construction. Therefore, each building needs to be inspected individually to determine the most efficient solution for the building energy refurbishment.

All campus buildings are built according to the building regulation at the time of construction. For instance, the best energy efficient building is the building according to the best voluntary energy classes of the current Danish building regulation. Compared to newer buildings that meet current regulations, older buildings are typically not energy efficient so there is a large potential for savings.

The energy management team for campus buildings only check the technical insulation, such as insulation used for pipes or in equipment rooms. There is however potential for retrofitting additional wall insulation, roof insulation and triple-glazed windows, all of which would improve the overall performance of the fabric. In general, large energy refurbishments are only made in combination with existing refurbishment plans that are not usually influenced by energy savings. The interviewed energy managers for campus buildings and an expert in building and construction, both believe that the insulation in the buildings is more important than the connection of buildings to the grid or the energy flexibility in buildings. However, both agree that energy flexibility can become more feasible in the future.

In this case, €1.34 million for 18 projects has been invested in energy-saving solutions that are predicted to obtain €0.27 million in energy savings. All projects have different payback periods. For example, photovoltaic installation is worth €0.54 million, for an annual saving of €94,000-€120,500, with a payback period of approximately 6 years. Other smaller projects, such as changing lighting sources and changing freezers have an estimated simple payback period of 9 years. This case study has told us all the reasons that campus universities find it difficult/impossible to implement energy flexibility.

3.4 Case 2 - building manager in energy flexible retail buildings

3.4.1 Introduction

Retail stores are one type of commercial building, selling a variety of products, owned or operated by retailers (Ma et al., 2017b). Larger retail stores are significant commercial energy consumers, as they have round-the-clock business operations (Robert P. King, 2003). The energy consumption of retail stores depends on the nature of the business, store format, products, shopping activities of customers and store equipment (Kolokotroni et al., 2015). There are many ways to control and, therefore, reduce energy use in retail stores. For instance, improving lighting system design and incorporating daylight-saving controls reduces energy costs in a building (Sheila J. Hayter, 2000). Retail stores can potentially provide various energy flexibilities, such as the flexible operation of refrigeration in supermarkets. Meanwhile, there are many stakeholders involved, including store managers, employees, and the customers.

This case study is based on two projects: the project - FlexReStore and a project on smart buildings in the Philippines (Ma et al., 2016). The FlexReStore project aims to investigate motivational factors among stores and cosumers, map the potential for flexibility among Danish stores, evolve retail store designs present in Denmark today to new designs that include flexible consumption, and to develop an Information Communication Technology (ICT) tool for flexible control of retail stores. The project of smart buildings in the Philippines aims to investigate the features and market potential of smart buildings in the Philippines.

This section introduces the store managers' DR control references and options regarding stakeholder engagement in energy flexible retail stores (Ma et al., 2017; Ma et al., 2018)

3.4.2 Methodology

This case study presents results from two countries: Denmark and the Philippines for a comparative study to fill the literature gap in the understanding of cross-national energy flexibility. Existing literature on the cross-national comparison in energy flexibility mainly focuses on energy consumption (e.g. (Mehrara, 2007)), renewable energy resources (e.g. (Huber et al., 2014)) and building energy use and regulations (e.g. (Iwaro and Mwasha, 2010)). There is no cross-national study on the energy flexibility of retail stores. There are many differences between Denmark and the Philippines, e.g. climate, regulation, economics, and culture. These differences can help us to further understand the similarities and differences between nations.

To investigate the demand response readiness of commercial buildings with the aspects of DR control preferences, customer engagement, and cross-national differences, this study targeted to survey altogether 200 managers of retail stores, 100 in Denmark and 100 Philippines. The questionnaire includes four parts based on the literature review and expert input as shown in 3.3.

The data collection in Denmark was conducted in April 2017, and in the Philippines in December 2016. Of these, 113 refused to participate due to the lack of interest or knowledge, resulting in a sample with a 43.5 % response rate. Among the 87 surveyed managers, 51 were from Denmark and 36 from the Philippines. The surveyed managers were either store managers or energy managers that were in charge of energy management in their stores.

Table 3.3 The content of the questionnaire.

Questionnaire section	Contents
Backgrounds	Number of employees Number of stores Store type
Control Strategies	Preferences for control options Concerns regarding control options
Motivation, barriers and concerns	Financial aspects Technological aspects Business aspects Legal and environmental aspects
Stakeholders' involvement	Employees and floor staffs Customers Utility companies

3.4.3 Results and discussion

Energy managers' preferences and concerns for DR control options

In the questionnaire, three energy control options are provided to the energy managers regarding the building energy flexibility:

- Manual control - buildings manually turn on/off equipment and change set points in reaction to high electricity prices
- Utility control - allow utility companies to send signals that would control electricity powered appliances in buildings
- Building automation - introduce an automatic system in buildings that can respond automatically to high prices

In Figure 3.1, the survey result shows that 48.2 % of energy managers were willing to use manual control to react to the electricity prices, whereas only 19.8 % and 25.6 % were willing for utility control and building automation, respectively, energy managers were mainly willing to use manual control for participating in the DR programs. The result corresponds to the current situation that building managers are more willing to participate in the implicate DR (e.g. peak/off-peak hours) compared to explicit DR (e.g. real-time pricing) (Ma et al., 2017a).

There is large discussion regarding aggregators and their business models. The result shows that 39.5 % of building managers are not willing to accept utility control compared to 30.2 % unwillingness of building automation. Therefore, aggregators might consider controlling building energy use via a building's own automation with price signals.

A Mann-Whitney U test indicated a statistically significant difference in the preference of manual control between Denmark and Philippines that the surveyed building managers in Denmark preferred manual control significantly more often than those in the Philippines (U = 433,5, p < .001). No statistically significant difference in preferences with utility controls or building automation between these two countries was observed.

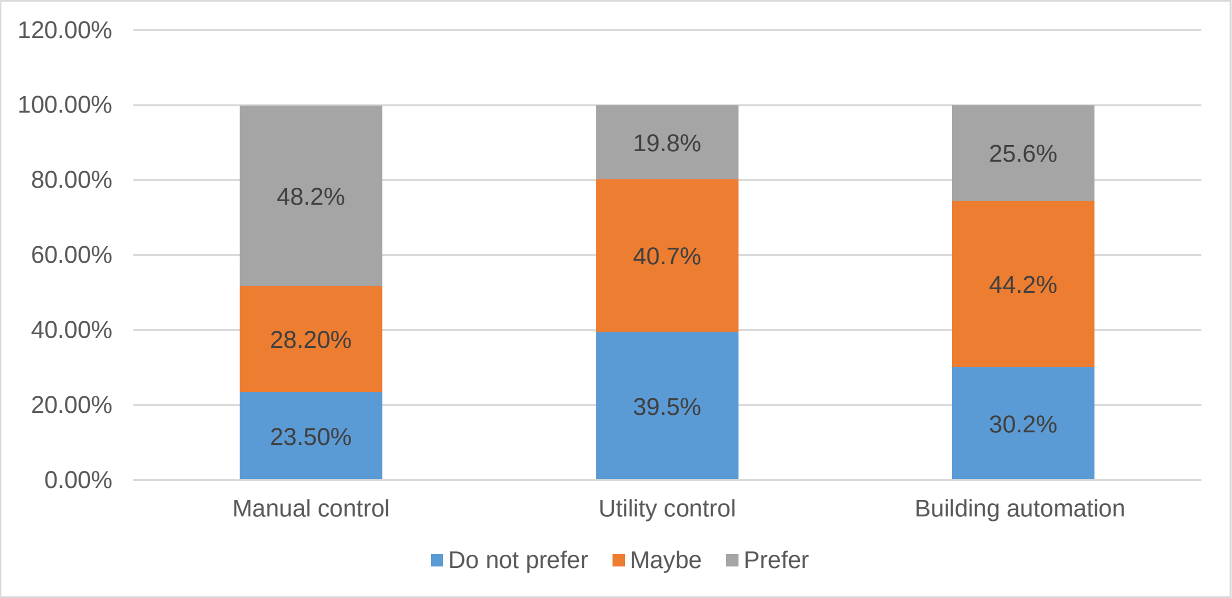


Figure 3.1 The percentage of surveyed managers' preferences regarding the control options.

Concerns for DR control options.

Figure 3.2 shows that the top four concerns for building managers are the 'indoor lighting', 'causing damages to equipment', 'interfering with business activities', and 'effective energy bill saving'. The result shows that the main concerns for building managers are maintaining the normal building operations and financial benefits. Figure 3.3 shows that the top 3 concerns for the Danish building managers are: 'interfering with business activities', 'indoor light' and 'compromising customers/occupants' experience'. Compared to the Danish building managers, Figure 3.3 shows that the building managers in the Philippines concern more about 'causing damages to equipment', 'effective energy bill saving', 'indoor lighting' and 'interfering with business activities'. Surprisingly, both the Danish and the Philippines' building managers are not concerned so much about 'privacy' or 'user-friendly control'.

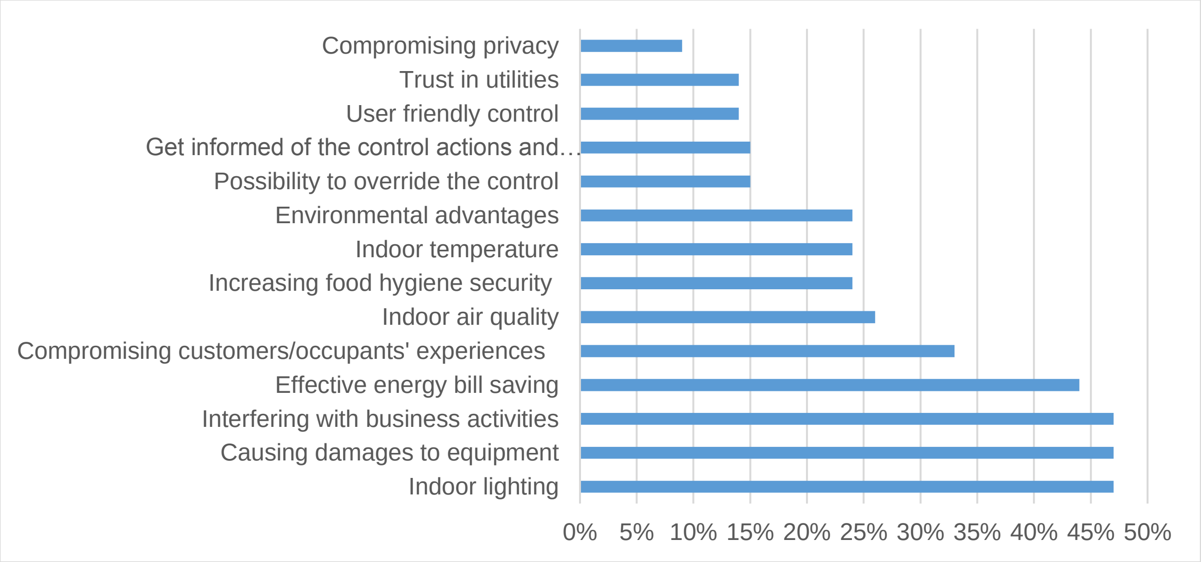


Figure 3.2 The percentage of surveyed managers’ concerns regarding DR control options. N = 87.

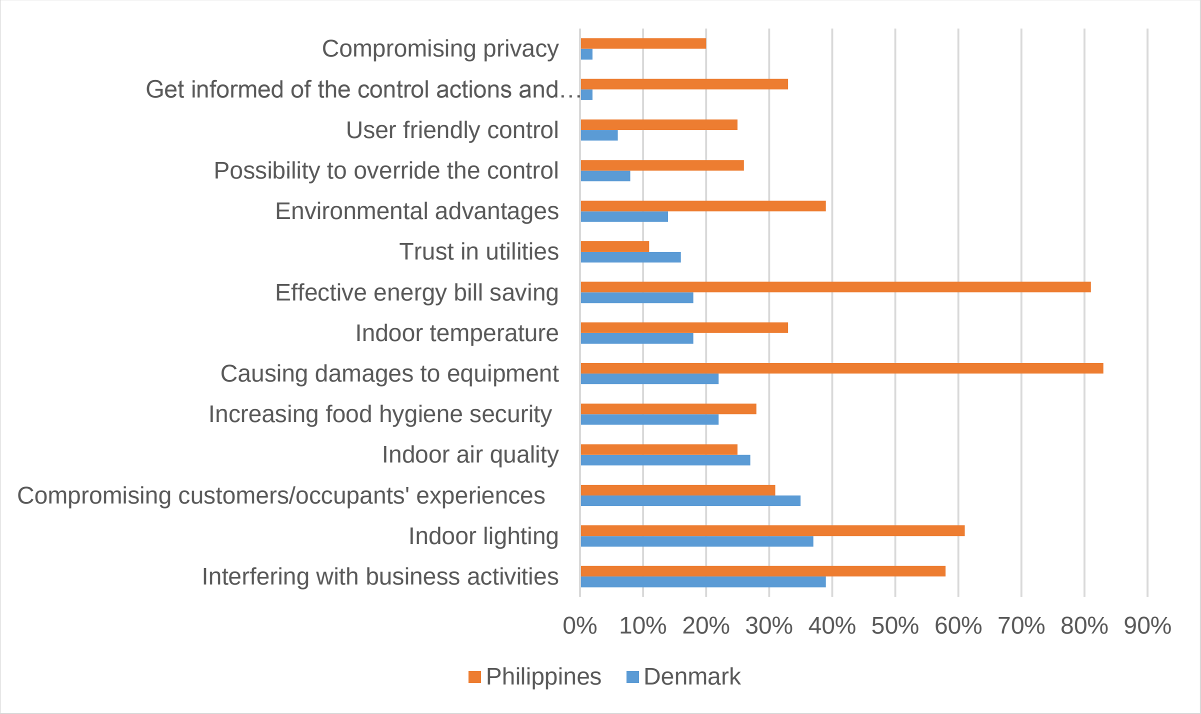


Figure 3.3 Comparison of the percentage of respondents reporting on being considered of given DR control options per surveyed country. N = 51 (Denmark), N = 36 (Philippines).

Motivation, barriers, and concerns for DR program participation

The factors that would influence building managers to participate in DR programs can be divided into financial, technological, business, legal and environmental aspects. A 5-point Likert scale from ‘0-not important at all’, ‘1-less important’, ‘2- neutral’, ‘3- slightly important’ to ‘4-very important’ was used to rank the importance of these influencing factors. Figure 2.4 shows the ranking of the influential factors that building managers consider to be important for participation in DR programs. Among the influential factors, Table 3.4 shows that store managers are more concerned about the business aspects; the legal and environmental aspects are the least important compared to other aspects.

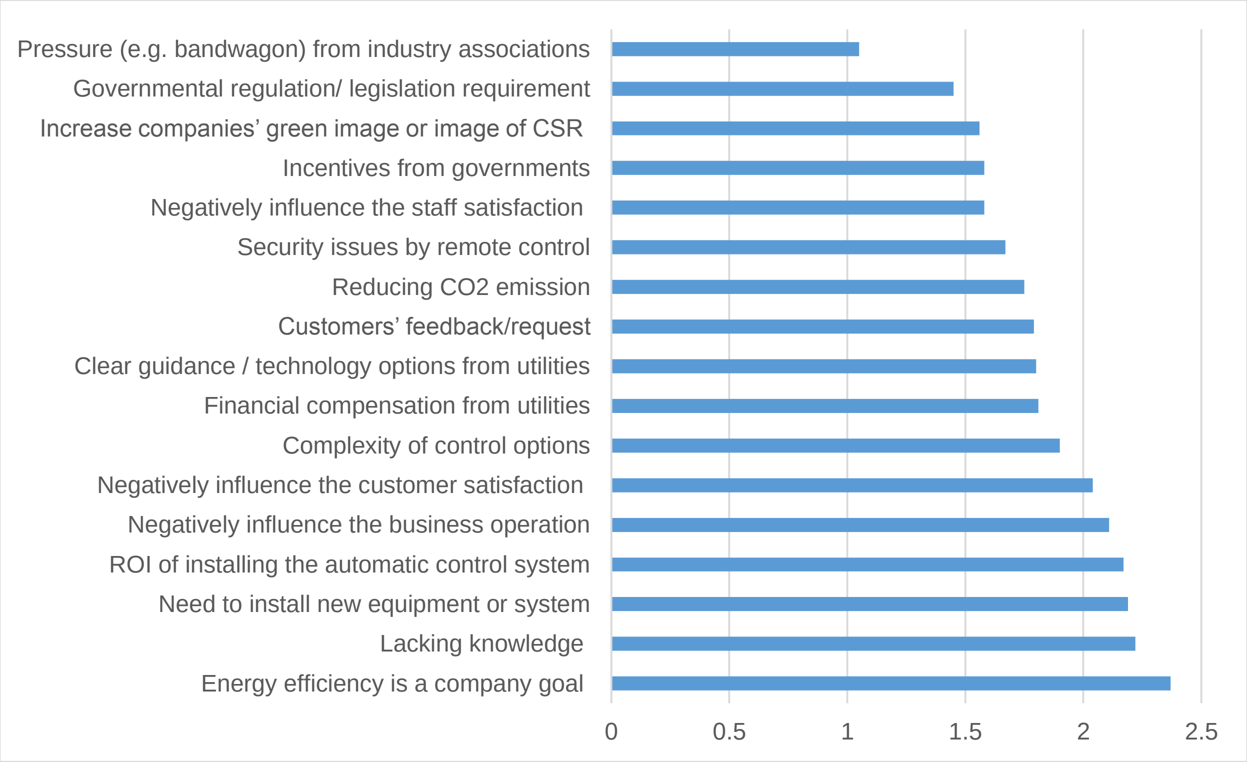


Figure 3.4 Influential factors that surveyed managers consider being important to DR program participation. N=87.

Table 3.4 Top Influential factors and the correspondent aspects.

Aspects	Top influential factors
Business	Energy efficiency is a company goal Dynamic control can negatively influence the business operation Dynamic control can negatively influence customer satisfaction (e.g. comfort)
Technology	Need to install new equipment or system The company is Lacking knowledge
Financial	The ROI (Return on Investment) of installing the automatic control system

Store managers in Denmark are more concerned about the surveyed factors compared to those in the Philippines (shown in Figure 3.5). Lack of knowledge was the only factor that store managers in the Philippines were more concerned about than those in Denmark. Figure 3.5 also shows, compared to the store managers in Denmark, store managers in the Philippines only consider 'lacking knowledge' and 'negatively influence the business operations' as being important for their participation in DR programs.

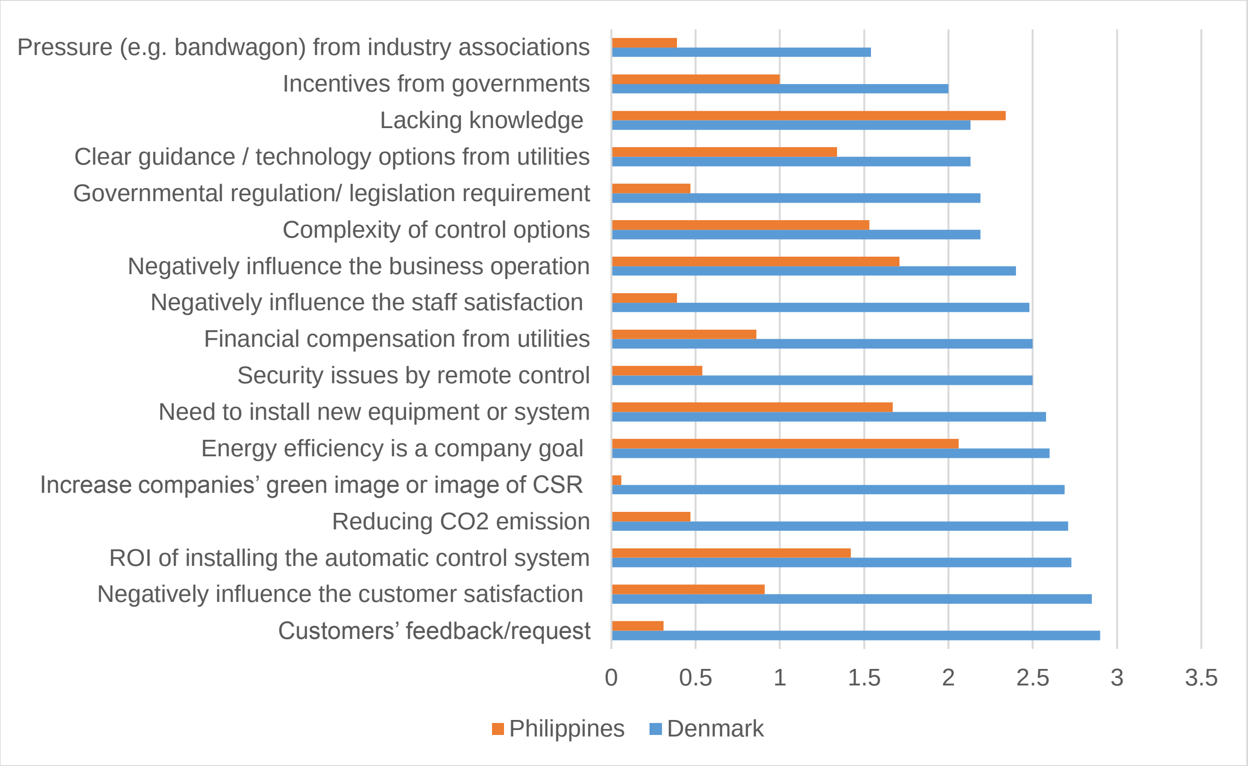


Figure 3.5 The comparison of influential factors that surveyed managers consider to be important to DR program participation N = 51 (Denmark), N = 36 (Philippines).

Stakeholders' participation in energy flexibility

Employees' participation in DR activities

Existing literature, e.g. (Christina et al., 2014), shows that some DR activities affect staff rather than customers, and staff are not often actively involved in DR activities. The surveyed result (Figure 3.6) shows that many store managers think employees should be informed regarding DR activities, but they do not think employees should be involved in the DR strategies or be rewarded for their involvement. Meanwhile, 51 % of store managers in Denmark think that employees should be involved in DR strategies, while only 5.6 % of store managers in the Philippines believe that employees should be involved.

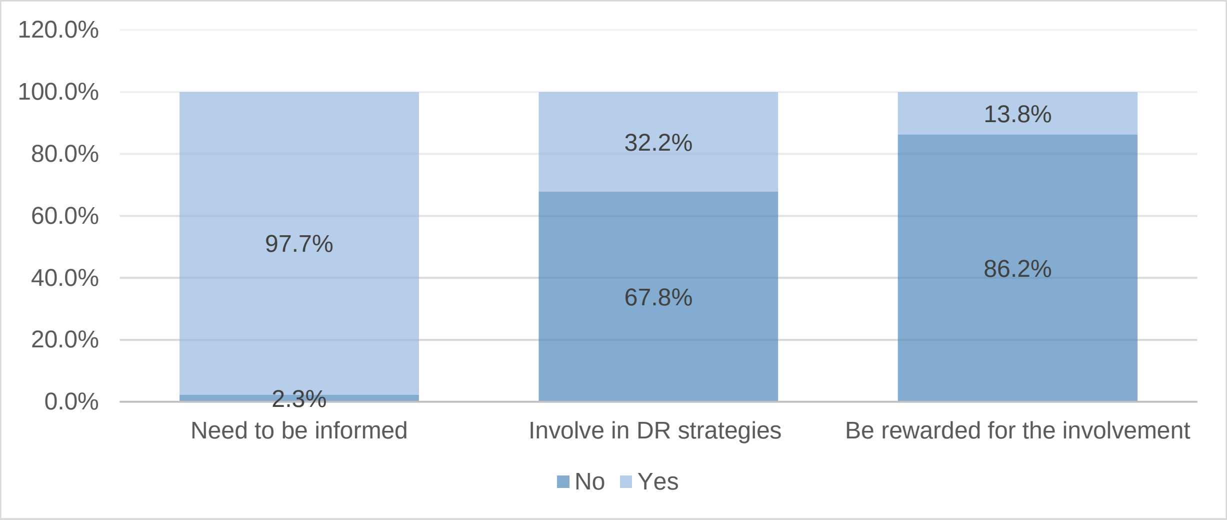
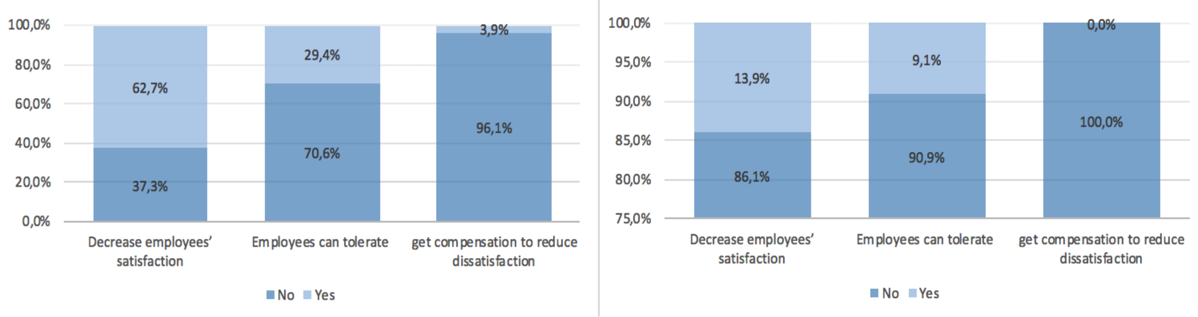


Figure 3.6 The percentage of surveyed managers’ opinions on if the employees should be informed of DR activities, involved in the activities or rewarded of the involvement in the activities. N = 87.

Of the surveyed store managers, 78.6 % believe that employees cannot tolerate the frequent indoor comfort changes by dynamic control. Yet, 97.7 % of the store managers do not think employees should get compensation for reducing their dissatisfaction. In Denmark, 62.7 % of the surveyed store managers believe that the dynamic control will decrease employees’ satisfaction, whereas only 13.9 % of store managers in the Philippines believe the same (Figure 3.7). On the contrary, more store managers in the Philippines (90.9 %) believe employees cannot tolerate the frequent indoor comfort changes through dynamic control compared to Denmark (70.6 %

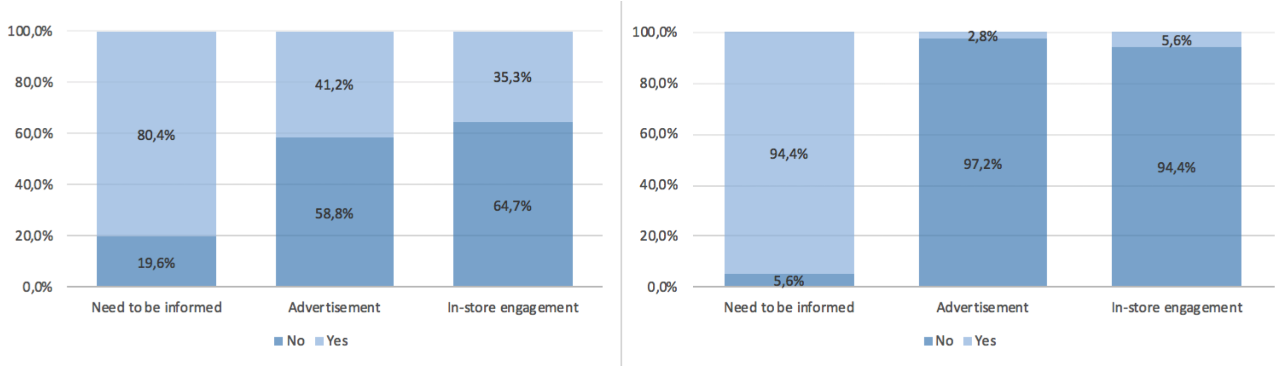


a) Denmark N=51 b) the Philippines N=36

Figure 3.7 The percentage of surveyed managers’ beliefs about employees’ satisfaction due to dynamic control.

Customers’ participation in the DR activities

Of all surveyed store managers, 86.2 % think that it is necessary to inform customers about DR activities in stores. However, 74.7 % of them do not believe that advertisement of an energy related program (in this instance energy flexibility), would increase the customers’ acceptance of frequent indoor comfort changes. In addition to this, 77% of them believe that the customers' in-store engagement/experience of an energy program would not increase customers' acceptance of frequent indoor comfort change. Compared to the Philippines, store managers in Denmark consider that more advertisement and in-store engagement can increase the customers' acceptance of indoor comfort change (shown in Figure 3.8).



a) Denmark N=51

b) the Philippines N=36

Figure 3.8 The percentage of surveyed managers' opinions regarding customers' reaction to the DR activities in stores.

Utilities' participation in energy management of retail stores

In Denmark, 50% of the surveyed store managers have received information regarding energy saving from the utilities, and 30 % have received information regarding energy efficiency programs or solutions for reducing their energy bills. The compensation for using less or more energy during a period is the subject with the least amount of information received from the utilities. The reason is most likely to be due to the absence of a DR market in Denmark. Compared to Denmark, store managers in the Philippines have received no information from the utilities. In the Philippines, electricity consumers normally receive information regarding electricity outage via media, not directly from the utilities.

Figure 3.9 shows, in general, a greater percentage of store managers in the Philippines expect more information to be received from utilities when compared to Denmark, maybe due to the lack of existing communication from the utilities. The main concern for the store managers is energy saving. Therefore, the store managers perhaps expect that the utilities could inform them more with 'information about energy saving' and 'consultation for reducing energy consumption'.

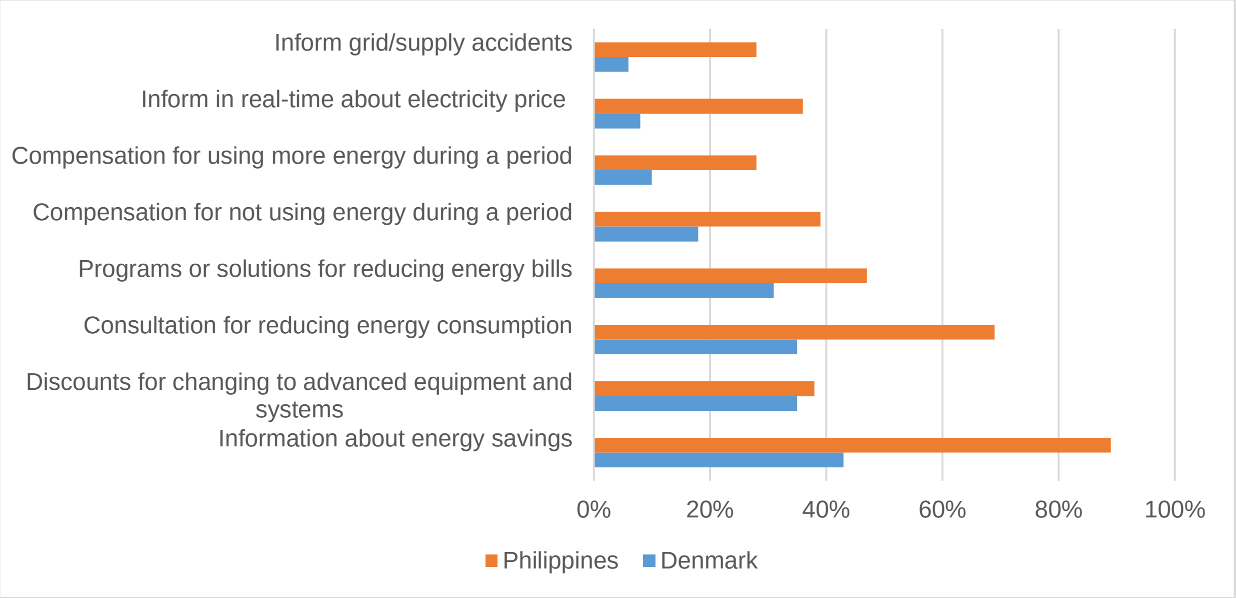


Figure 3.9 The percentage of the surveyed managers' opinions regarding expectation to the utilities. N = 51 (Denmark), N = 36 (Philippines).

3.5 Conclusions

Two cases in this section discuss the role of building managers in obtaining energy flexible buildings. The case study in campus buildings shows that there are three important parts for the readiness of energy flexible buildings: building automation, building-to-grid, and energy flexibility market, along with the impacts of regulation and policies, stakeholder collaboration and integrated building automation. However, none of the three aspects are ready in the current situation in Denmark. As noted in the introduction to this chapter, there is currently no market for energy flexibility as such. Consumer must exceed demand above 1MV to participate in ancillary markets and aggregators at the demand side are currently not allowed to participate in the market at all. Although buildings can choose hourly electricity price, the energy bill is not significantly different from the fixed price.

Building managers believe that buildings can provide energy flexibility through building automation and distributed energy resources. However, the main challenge for buildings is still energy efficiency due to national and international policies and monetary benefit from the energy saving. Based on the first case study presented here, the main barriers for buildings to provide energy flexibility are 1) building refurbishment is needed in many buildings, 2) the monetary benefit of providing energy flexibility to the grid is not significant, 3) building management systems need to be upgraded and to respond properly to activities in rooms and to the requirements of the grid.

The second case study investigates the opinions of building managers of retail buildings regarding participation in DR programs concerning three aspects: energy control preferences, stakeholder engagement, and cross-national differences. The results show that building managers typically prefer manual energy control, compared to utility control or building automation. Building managers prefer more self-control. The main reasons are due to the potential interference of the retail stores' business activities caused by third-party control. Building managers' concerns related to the manual control preferences are equipment damage, saving on bills, indoor temperature, and indoor lighting.

There are six factors that building managers in retail buildings believe are important to DR participation: company goals, lacking related knowledge, new equipment installation, Return on Investment (ROI), business operation and customer satisfaction. Surprisingly, retail store managers did not believe that legal and environmental factors are important influences on their DR participation.

Regarding stakeholder engagement, the case shows that building managers in retail buildings believe that their employees and customers should be informed regarding the stores' DR participation. This is due to the potential interference of employees' working environment and customers' shopping experience. However, building managers prefer not to include either their employees or their customers in the DR strategies or activities. Meanwhile, building managers expect to receive more information regarding energy bill reduction or energy saving from the utilities. This result shows that the focus for building managers remains on energy efficiency, and not energy flexibility. Potential financial benefits are their main incentive for altering their energy consumption.

4. Occupants in Energy Flexible Buildings

4.1 Introduction

Demand Response (DR) is defined by the European Commission as “voluntary changes by end-consumers of their usual electricity use patterns - in response to market signals” (Annala and Honkapuro, 2016). Through DR, consumers can provide flexibility by load shifting, peak shaving or filling (Ma et al., 2017b). For example, consumers can shift to an alternative type of energy source during periods of peak demand, thereby alleviating stress in the grid; this shift can be controlled either manually or automatically (Patteeuw et al., 2016). Peak shaving refers to the reduction in energy use during periods of peak demand and filling refers to the movement of consumption to times when demand from the grid is low.

Occupants have an important role in enabling energy flexibility from buildings. Their acceptance and adoption of energy flexibility solutions in buildings influences the viability and scope for load shifting, peak shaving or filling. Research shows that occupants behaviour significantly impacts the use of energy (e.g. HVAC, lightings, appliances and building controls) (O'Brien and Gunay, 2014, Gulbinas et al., 2014, Nguyen and Aiello, 2013, Roetzel et al., 2014, Zeiler et al., 2009). Consumers’ energy consumption pattern, comfort, and preferences vary further due to consumers’ behaviours (Zanjani et al., 2015).

However, changing consumer behaviour is a challenge when it comes to obtaining energy flexibility from buildings (Billanes, 2017). Occupants spend approximately 85 % of their time indoors (Kjærgaard et al., 2016). It is well established that occupant behaviour can adversely affect the energy performance of buildings (Masoso and Grobler, 2010). A study of offices in Africa and Botswana shows that 56% of the energy is consumed during non-working hours because occupants do not turn off equipment when they leave offices (Masoso and Grobler, 2010).

Therefore, to aid understanding of this issue, this chapter aims to investigate the role of occupants in energy flexibility within three types of buildings: office buildings, campus buildings, and residential buildings.

Table 4.1 Summary of data collection and results.

Purpose:	Types of Building	Methodology	Targeted aspect	Result highlight
Occupants' motivation and opinions	Campus buildings	Questionnaire	• Occupants' awareness • Occupants' satisfaction with the energy performance in buildings • Occupants' acceptance of energy flexible buildings	• Occupants are satisfied with the indoor comfort • Occupants cannot tolerate frequent changes of indoor comfort • Occupants think that only the indoor comfort of hallway and canteen can be adjusted frequently • Occupants believe that the investment in solar panels and energy storages are feasible, but not combined heat and power. • Occupants believe that university plans for green image and energy saving can improve occupants' acceptance of frequent changes of indoor comfort
Energy Flexible office end-users, motivating factors	Office buildings	Questionnaire	• Perception of renewable energy usage • Perception and attitude towards smart grid, smart appliances, and smart meters • Willingness to use smart appliances in offices • Motivation to accept a flexible energy usage	• The use of renewable energy instead of fossil fuels to fuel HVAC systems in office buildings is recognized as a very important action; • The smart grid concept is unfamiliar to almost half of the respondents; • The most suitable smart appliances accepted to be remotely controlled are the air conditioning and the heating system; • The possibility to override the control, not compromising the privacy and environmental advantages are the main motivating conditions for accepting the remote/follow the manual control of smart appliances; • The main motivating factors to accept a flexible energy usage are the possibility to see how much the electricity usage is minimized and the amount of saved money; • The most effective information to be displayed on a monitor is the amount of saved energy; • Half of the respondents think that smart grids will have a neutral influence on their work.
Residents 'perceptions	Residential	Questionnaire	• the willingness of occupants to use smart technologies and change their energy use behaviour • how well building users are prepared to contribute to the energy flexibility of their buildings • building user perceptions of smart grids and their readiness to adopt smart technologies	• Awareness of smart grids is the highest among respondents aged 20–29 years • Willingness to use smart technologies and change energy behaviour are interdependent • Potential flexible building users were found to be 11 % of the respondents

4.2 Background

According to IEA EBC Annex 67, the energy flexibility of a building is '…the ability to manage its demand and generation according to local climate conditions, user needs, and energy network requirements' (Jensen, 2017). Buildings can supply flexibility services in different ways, and the buildings' ability to provide energy flexibility is influenced by several factors (Junker et al., 2018): (1) its physical characteristics, e.g. thermal mass, insulation, and architectural layout, (2) its technologies, e.g. ventilation, heating, and storage equipment, (3) its control system that enables user interactions, and the possibility to respond and react to external signals, e.g. electricity price or CO_2 factors, and (4) the occupants' behaviour and comfort requirements.

Therefore, occupants have an important role in ensuring that strategies for energy flexibility are viable. Occupants approximately 85 % of their time indoors (Kjærgaard et al., 2016). Their acceptance and adoption of energy flexible solutions in buildings has an influence on the scope for energy flexibility in any given building (Billanes et al., 2017).

In the literature published to date, occupant comfort has primarily been considered for energy efficiency and not DR (Chen et al., 2015). Similarly, occupant comfort has only been addressed to a limited extent in the research exploring energy flexible buildings (Behl and Mangharam, 2015). In the research focused on energy flexibility, one of the remaining questions is to understand whether occupants would accept the frequent changes to the internal environment and general operations that may result from changes in energy use based on external signals (Le Dréau and Heiselberg, 2016). Consumers' energy consumption patterns, comfort, and operational preferences vary due to the occupants' behaviours, and changing consumer behaviour is a challenge when considering energy flexibility (Zanjani et al., 2015). However, many experiments have relied on the assumption that occupants will accept control of the indoor temperature based on an external signal (Le Dréau and Heiselberg, 2016). Therefore, there is an urgent need to investigate the occupants' roles and acceptance of the energy flexibility in buildings.

There are three basic categories of buildings in the context of the scale of energy use: industrial, commercial and residential buildings (Samad and Kiliccote, 2012). Different types of buildings can provide different energy flexibilities, and the occupants in different types of buildings have different energy use patterns, comfort needs, and preferences. Commercial buildings have an important role for the demand side energy flexibility because of their high energy consumption, a variety of energy flexibility resources that are available to them, and the centralized control via building control systems (Ma et al., 2017b).

One type of buildings with potential high energy flexibility are university campus buildings. When taken as a whole, a university campus is a relatively large energy consumer and, often, the majority of the buildings are equipped with some sort of building control systems. Building automation, together with a Building Energy Management System (BEMS), can help increase the energy efficiency of the campus buildings and the potential of providing energy flexibility to the grid, due to larger automation in the control of energy use (Barbato et al., 2016). There are three types of occupants in the campus buildings, academic staff, administration staff and students. Students perform learning activities in the campus buildings, and the indoor environment can influence their learning performance. Various systems that control the indoor environment create a power demand, due to heating, cooling ventilation and lighting.

Office buildings are a globally prevalent type of commercial building that represent a suitable building typology for Demand Response strategies, due to their extensive demand of Heating, Ventilation and Air Conditioning (HVAC) systems, resulting from high occupancy, large use of appliances and high percentage of window to wall areas on external façades (Sandels et al., 2016). Office buildings, particularly more modern examples, are often equipped with Building Energy Management Systems (BEMS) (Djuric and Novakovic, 2012) to monitor and control the HVAC system and plug-loads with respect to comfort levels, occupancy and weather dynamics and can actively contribute to energy flexibility potential operation.

The work of Billanes et al. (Billanes et al., 2017) examines stakeholders' concerns and behaviours that affect energy performance in office buildings and discusses possible technical solutions -with the integration of distributed energy resources, building management and control systems – to improve energy flexibility.

4.3 Case 1- Occupants in energy flexible campus buildings

4.3.1 Introduction

This case is based on a project conducted by the University of Southern Denmark. The project aim was to investigate the occupants' experience of energy control and indoor comfort and their option regarding energy flexibility in campus buildings (Ma, 2018).

4.3.2 Methodology

A questionnaire was distributed by email via the secretary at the faculty to all students enrolled at the faculty. According to Facts and Figures by the university (Syddansk Universitet, 2016), there were 3,377 students at the end of 2015. In total, 267 fully completed and usable questionnaires were received, resulting in a response rate of 7.9%.

The distribution of the surveyed students was 68.9% bachelor and 31.1% master students. This distribution corresponds exactly to the distribution of bachelor and master graduates from the faculty of engineering at the university in 2015 and thus verifies that the data collected is representative (Syddansk Universitet, 2016). The gender of the surveyed students was split between 78.3% and 21.7% for males and females respectively, and the age distribution was 76.4%, 19.1%, 3.7% and

0.8% for 18-25, 26-31, 32-40 and 40+. These distributions are to be expected when conducting a survey in an engineering faculty at a university of this type.

Most of the surveyed students had been enrolled at the university for 1 to 3 years (47.2%). A large number of respondents have been enrolled for 3 to 5 years (30%). Few surveyed students have been enrolled for more than 5 years (3.8% for 5-7 years, and 0.7 % for more than 7 years) and 18.4 % have been enrolled for less than a year. This corresponds with university records on the distribution of periods of enrolment for all students at the time.

Regarding the number of hours per week the surveyed students spend on campus, 56.6% of the surveyed students spent 15-25 hours per week, and 22.1% spend 5-15 hours, 11.2% spend 26-35 hours, and 2.2 % spend more than 35 hours a week on campus. Only 7.9 % of the surveyed students spent less than 5 hours a week at the university. Among the 267 surveyed students, the top two locations where students spend most of their time on campus are the classrooms and the group rooms. The result corresponds to the typical workload and locations in terms of teaching hours and locations at the Faculty of Engineering.

Measurement

To test the proposed content of the survey, interviews with 10 students were conducted to ensure content validity. In addition, two energy staff responsible for the energy management at the university were interviewed to validate the proposed content from a building and energy management perspective. The survey design was developed based on the literature and interview analysis results.

To validate the quality of the survey results, this research designed three questions to test surveyed respondents' competence in energy-related knowledge and experience about energy activities and management in campus buildings. The analysis result from this exercise is presented as a descriptive analysis result in the next section.

4.3.3 Results and discussion

Occupants' preferences on frequent change of indoor comfort

On average, the surveyed students do not agree either to change the classroom temperature ($t(266)=-2.00$, $p <0.05$) or ventilation frequently ($t(266)=-4.04$, $p \leq 0.0005$). However, the surveyed students believe that the frequent changes in indoor comfort in the classrooms can influence the teaching and learning performance ($t(266)= 3.5$, $p \leq 0.001$)).

Occupants' preferences on locations of potential indoor comfort changes

There are different types of space in campus buildings, e.g. classrooms, labs, and office. The survey result shows that hallways and canteens are the top two places the surveyed students believe that the comfort can be adjusted frequently as it will not influence their activities. Other places, such as classrooms, auditorium, labs, group rooms, and offices are not accepted for frequent changes in temperature, light or ventilation.

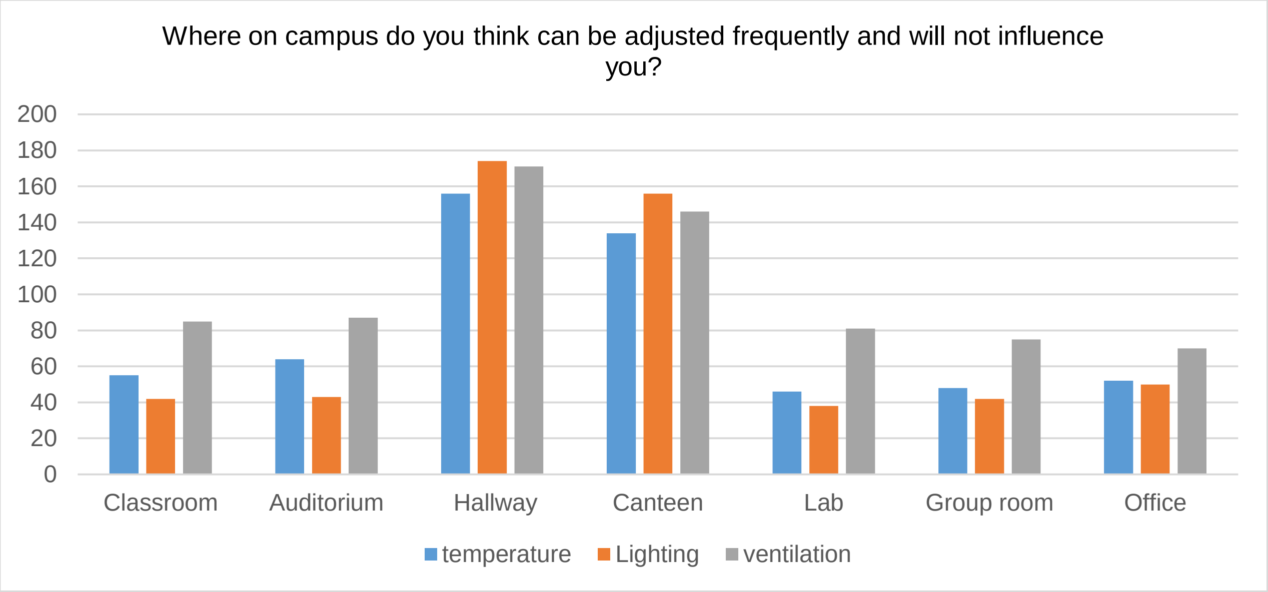


Figure 4.1 Occupants' preferences on locations of potential indoor comfort changes.

Occupants' preferences on the investment of distributed energy resources on campus

The surveyed students believe the university should invest in solar panels (t(266)=8.78, p≤0.0005) and energy storages (t(266)=2.586, p≤0.01), and they have the statistically significant opinions regarding the investment in electric vehicle charging station/facility (t(266)=-1.24, p=0.217) or wind turbines (t(266)=-1.24, p=0.217). Meanwhile, they are negative regarding investments in combined heat and power (t(266)=-2.59, p≤0.01).

Regarding potential installation of wind turbines on campus, 40.8 % of the survey students believe that noise from wind turbines will affect their concentration, while 36 % believe it will not. There is no statistically significant relationship between the results and the gender with two degrees of freedom (2.10, p=0.35).

On average, the surveyed students do not think the availability of electric vehicle charging points on campus will affect their choice of driving electrical cars (t(266)=-2.21, p≤0.05).

Occupants' preferences on students' motivation for the acceptance of energy flexibility in campus buildings.

More than half of the surveyed students believe 'University plans to become a green intelligent university', 'University tries to reduce the energy consumption', 'University tries to reduce the energy bill, and will put the saved bill into campus facility improvement' can motivate students to accept frequent changes of the indoor climate. Meanwhile, the image of 'green intelligent university' is the most popular motivation for students to accept frequent changes of the indoor climate. Comparatively, financial benefits to the university or students (reduce energy consumption or save energy bill to invest in more on-campus facility improvement) are less attractive for the surveyed students.

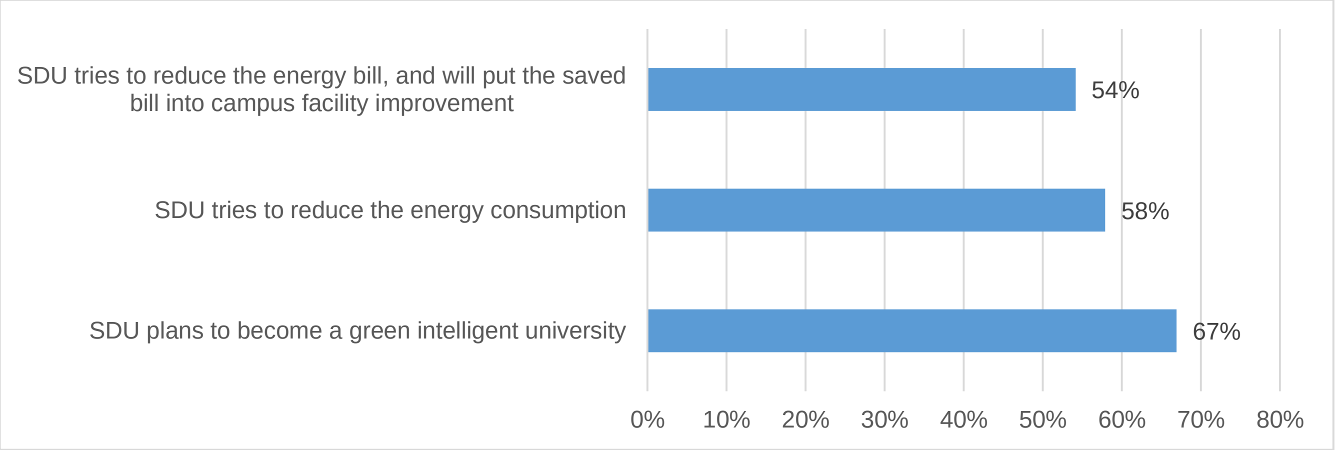


Figure 4.2 Occupants' preferences on students' motivation for the acceptance of energy flexibility in campus buildings.

4.4 Case 2 - Large-scale Italian survey

4.4.1 Introduction

The energy flexible potential of office buildings from an end-users' perspective was investigated through the development of a large-scale survey conducted on the public employees of the Province of Bolzano, in Northern Italy. The questionnaire dealt with smart grid-related services and a list of motivating factors were also included. The purpose was to investigate the related office end-users' perception and acceptance to change their energy use behaviour and contribute to the energy flexibility of their buildings. In the following section, the methods for designing the questionnaire and conducting the survey are presented.

4.4.2 Methodology

This study aims to survey a large representative sample of office end-users in Italy. Based on the work of (Li et al., 2017), an online questionnaire was prepared in two languages, Italian and German, and the questionnaire link was circulated in the offices of the Province of Bolzano during the period February – June 2017. The survey was addressed to all categories of people fully working in the offices and the survey was closed when 922 completed questionnaires were collected.

The questionnaire consisted of 18 multiple-choice questions organized in three main parts, as presented in Table 3.2: (1) social-demographic data, (2) perception of renewable energy usage and (3) smart grids, smart appliances, and smart meters. A short description of smart grids and their functioning principles was provided in order to give an overview to the respondents about this topic.

Table 4.2 The content of the questionnaire.

Questionnaire section	Contents
Social-demographic data	Gender and age Educational level Position Office typology
Perception of renewable energy use	Knowledge of renewable energy sources Importance of using renewable energy
Smart grids, smart appliances, and smart meters	Perception and attitude towards smart grid technologies Willingness to use smart appliances in the office Motivation to accept a flexible energy usage

4.4.3 Results and discussion

The group characteristics of the survey respondents are shown in Table 4.3. The majority of the respondents had a position of either ‘employee’ (77%) or ‘manager’ (13%) and worked in a ‘single office’ (42%) or ‘office shared with one colleague’ (40%).

Table 4.3 Sample characteristics (N=922).

Characteristics	Survey sample
Gender	39% male, 61% female
Age (years old)	< 30: 4%, 30-39: 17% 40-49: 37% 50-59: 35% 60-69: 7%
Educational level	Secondary school or lower: 3% High school: 53% University level: 39% Ph.D.: 5%
Position	Employee: 77% Manager: 13% Intern: 0.4% PhD/researcher: 0.1% Team leader: 6% Team member: 2% Other: 2%
Office typology	Single office: 42% Shared office with another colleague: 40% Shared office with two other colleagues: 7% Shared office with 3 or more other colleagues: 6% Open space: 2% Other: 2%

Perception of renewable energy usage

The survey result shows that 65% of the respondents declared that they were aware of renewable energy sources, whereas 33% admitted knowing only ‘a little bit’ about the topic and only 2% stated to be unaware.

Concerning the general question related to the importance of using renewables instead of fossil fuels (Figure 4.3), a Likert scale (from ‘1-not at all important’ and ‘5-very important’) was used. A percentage of 72% of the respondents voted the option ‘5-very important’ (against 0.4% for the option ‘1-not at all important’). Similarly, for the question related to the importance of using renewables specifically in the context of the offices (Figure 4.4), 57% chose as top option ‘5-very important’ compared to the 1.2% of the option ‘1-not important at all’).

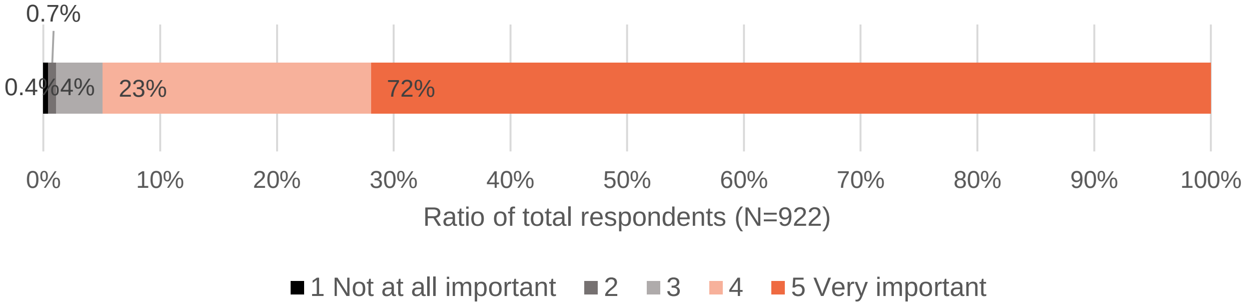


Figure 4.3 Importance of using renewables instead of fossil fuels.

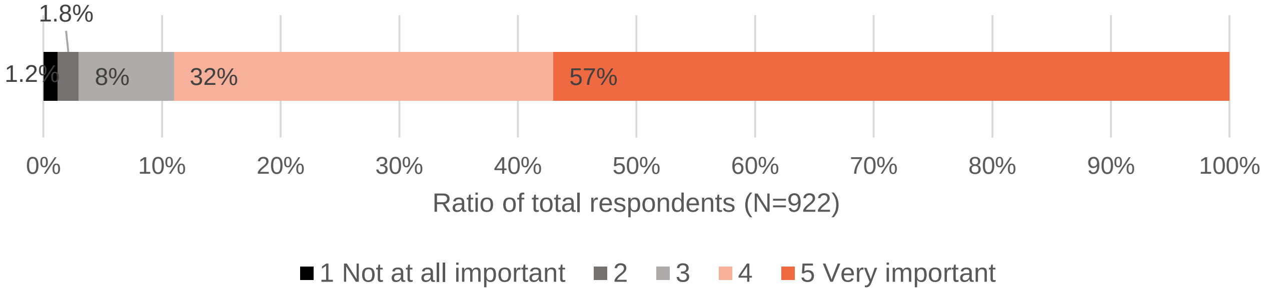


Figure 4.4 Importance of using renewables in offices.

Perception and attitude towards smart grid technologies

After providing a brief introduction on the concept of smart grids, the respondents were asked about their knowledge of smart grids before taking the survey. Five options were presented from ‘never heard of it’ to ‘know a lot about the concept’. As shown in Figure 4.5, 45% of the respondents didn’t know about the concept and only a small number of them (2%) stated that they already knew a lot about it. Therefore, according to the answers, we can state that the majority of the respondents, even if already informed about the concept of smart grid, were not aware of its features, neither about the potential benefits of its application.

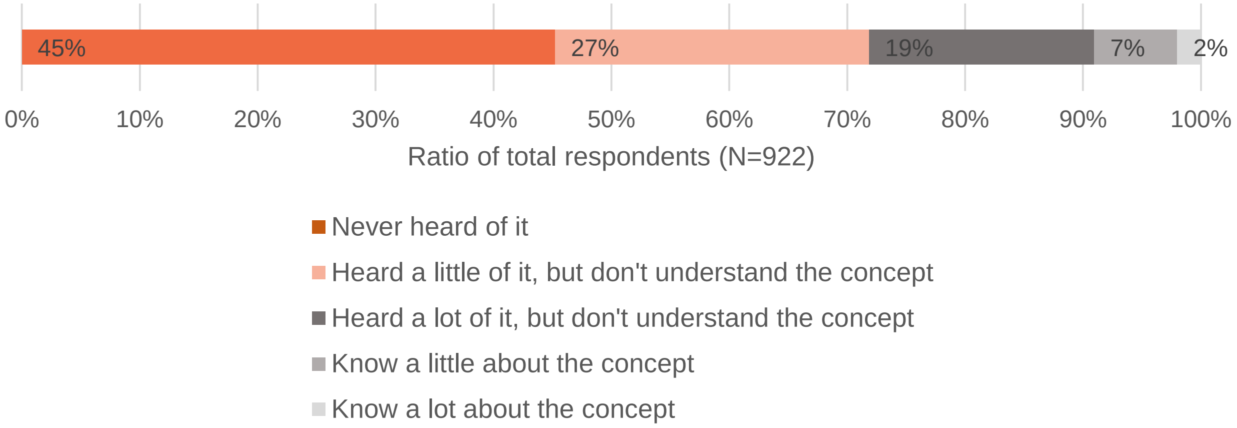


Figure 4.5 Familiarity with smart grid.

Willingness to use smart appliances in the office

Some questions were provided to assess the willingness to use smart appliances in the office. The first question was related to the willingness to let some smart appliances be remotely controlled by the electricity utility (Figure 4.6). A Likert scale was provided from '1-not willing at all' to '5-really willing' as choices. The majority of the respondents stated that they would be positive to allow remote control for all the appliances and especially the 'heating system' (42.5%) and the 'air conditioning' (41.8%), with respect to thermal comfort conditions. The willingness to use an 'electric vehicle' with a smart charging and discharging system also obtained promising results (39.5% stated the 'really willing' option).

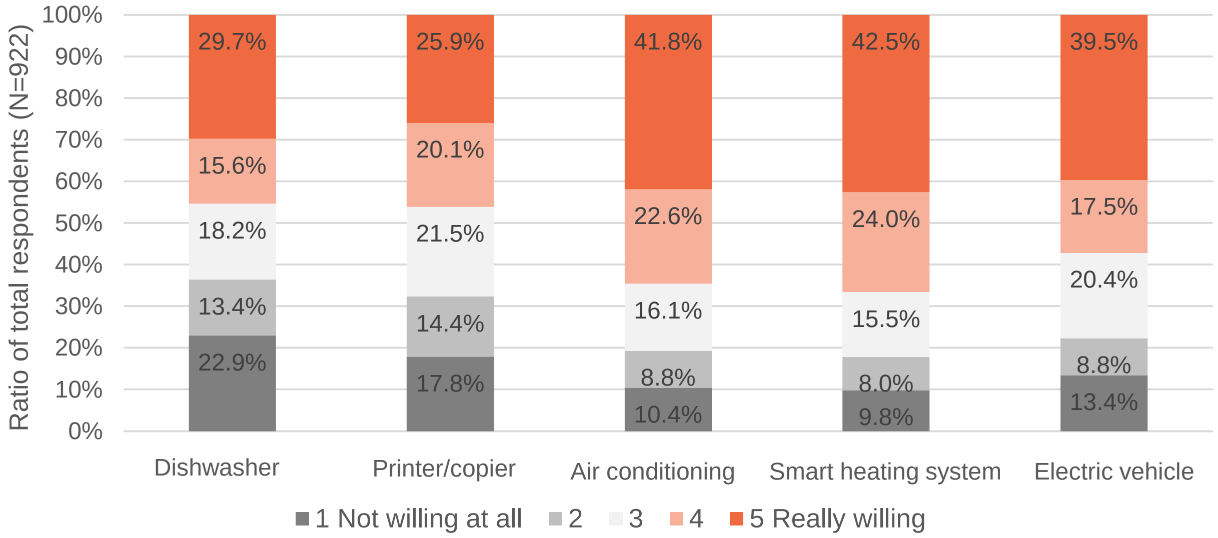


Figure 4.6 Willingness to let some smart appliances be remotely controlled by the electricity utility.

The second question was related to the willingness to follow the messages shown on a monitor or a smartphone to manually turn on some smart appliances at the recommended time (Figure 4.7). A

Likert scale was provided from ‘1-not willing at all’ to ‘5-really willing’ as choices. The level of willingness is comparable with the results of the previous questions, in fact the majority of the respondents were ‘really willing’ to allow remote control for all the appliances and especially for the ‘heating system’ (40 %), the ‘air conditioning’ (40 %) and the smart control of ‘electric vehicles’ (38.3%).

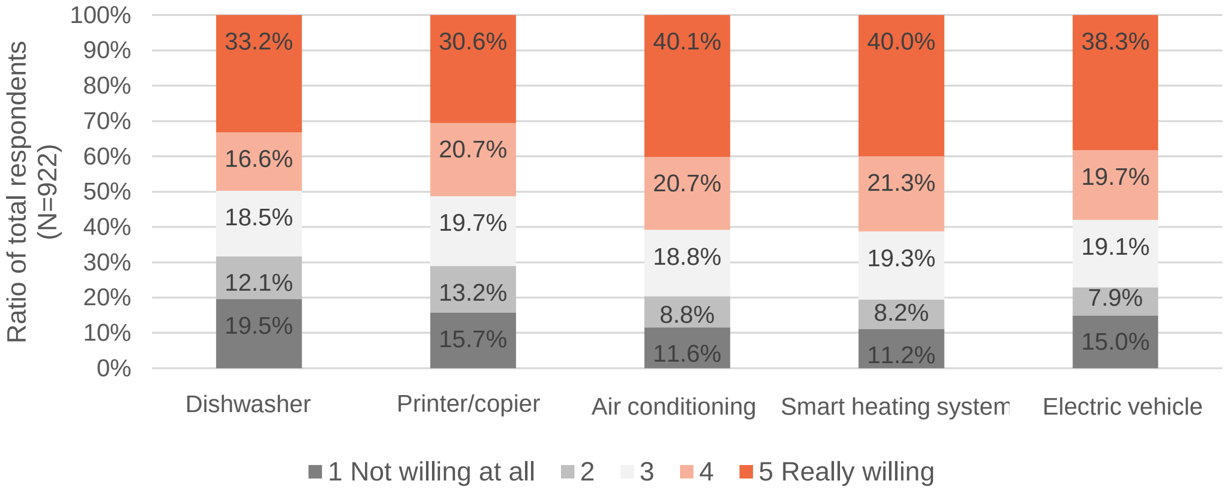


Figure 4.7 Willingness to follow the messages shown on the office monitor or smartphone to manually turn on some smart appliances at the recommended time.

Motivation to accept a flexible energy usage

The respondents were questioned about a list of motivations for accepting a flexible energy usage. Figure 4.8 shows the conditions for respondents to accept the remote control of some appliances by the electricity utility. The top condition was ‘possibility to override, at any time, that control’ (78 %), meaning that the users, even if motivated in accepting a remote and flexible control, were not willing to give away the possibility to manage the operation of the building themselves. Another key issue, stated by the 75% of the respondents, was ‘not compromising privacy’, while providing ‘environmental advantages’ was an important issue for 74 % of the respondents.

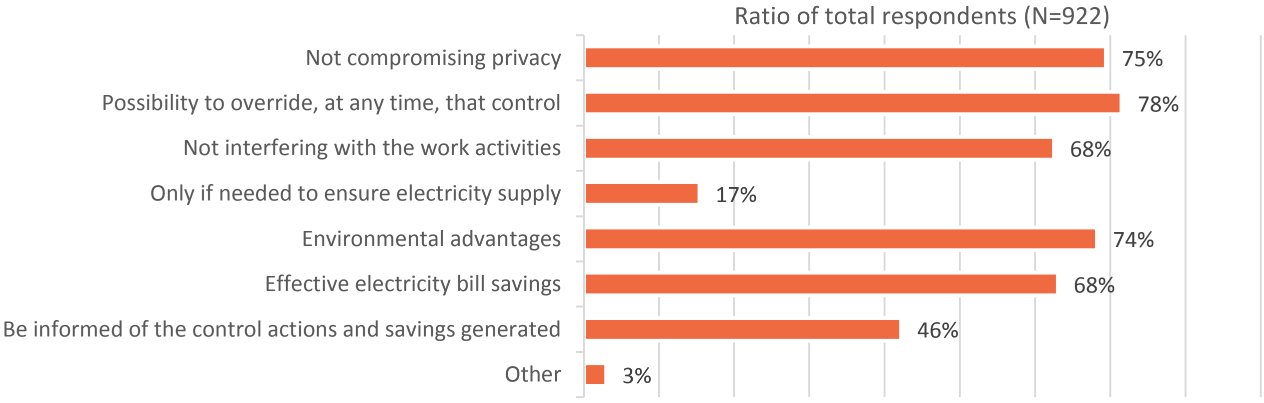


Figure 4.8 Conditions to accept the remote control of some appliances by the electricity utility.

The questionnaire asked about the specific requirements respondents felt they needed to follow from the electricity utility and manually control the appliances. The top three conditions were the same of the previous questions, but in a different order of importance: ‘environmental advantages’ (72%), ‘not compromising privacy’ (71%) and ‘possibility to override, at any time, that control’ (70%).

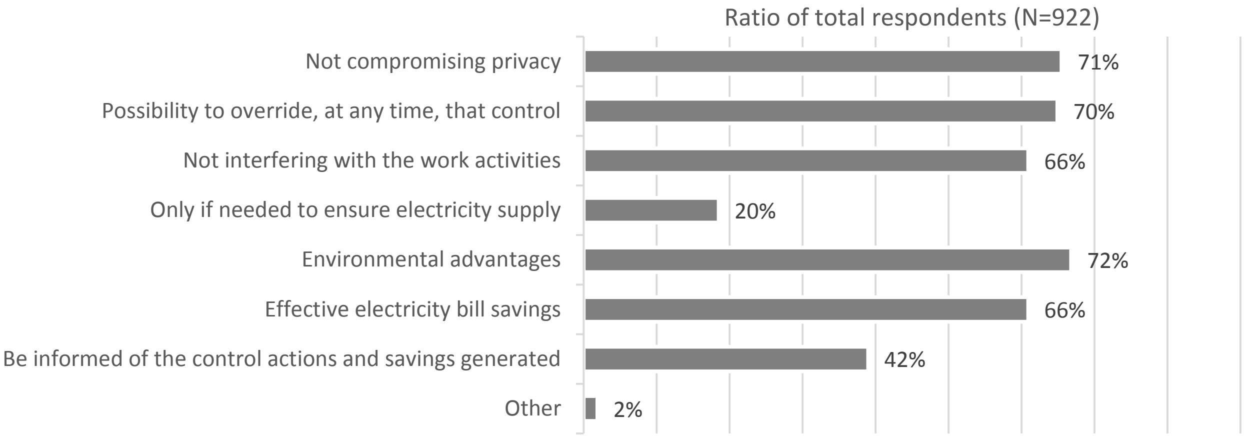


Figure 4.9 Conditions to follow the recommendations from the electricity utility and manually control the appliances.

Figure 4.10 shows the reasons for the respondents for not accepting the remote control of some appliances by the electricity utility. The top three conditions were ‘interference with privacy’ (75%), ‘no override function’ (75%) and ‘risk of interference with the work activities’ (66%).

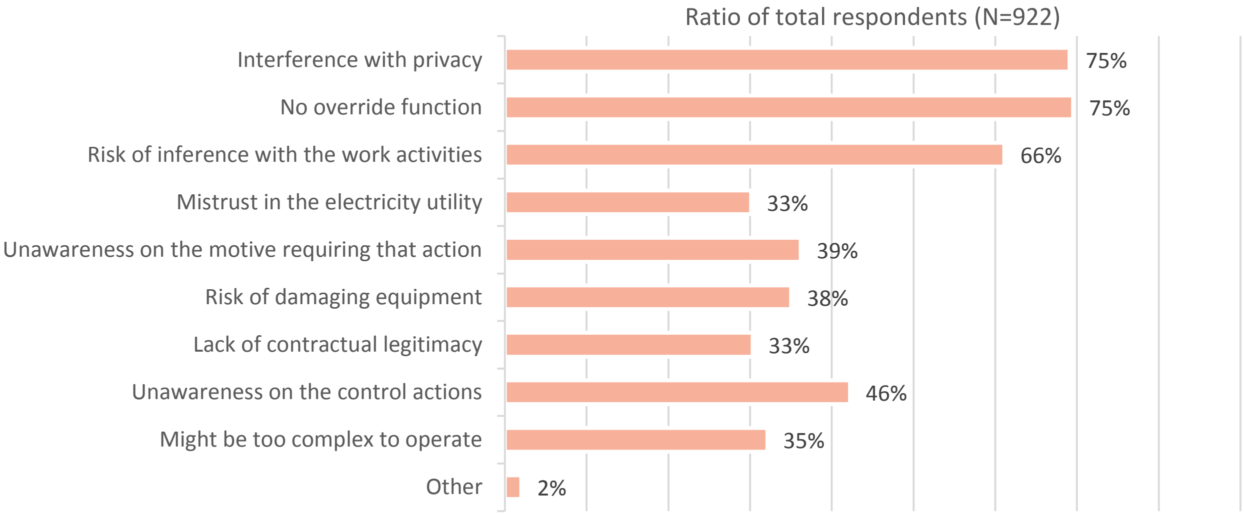


Figure 4.10 Reasons to not accept the remote control of some appliances by the electricity utility.

Figure 4.11 shows the reasons for the respondents to not follow the recommendations from the electricity utility and manually control the appliances. The top three conditions were ‘interference with privacy' (65%), 'no override function' (65%) and 'risk of interference with the work activities' (59%).

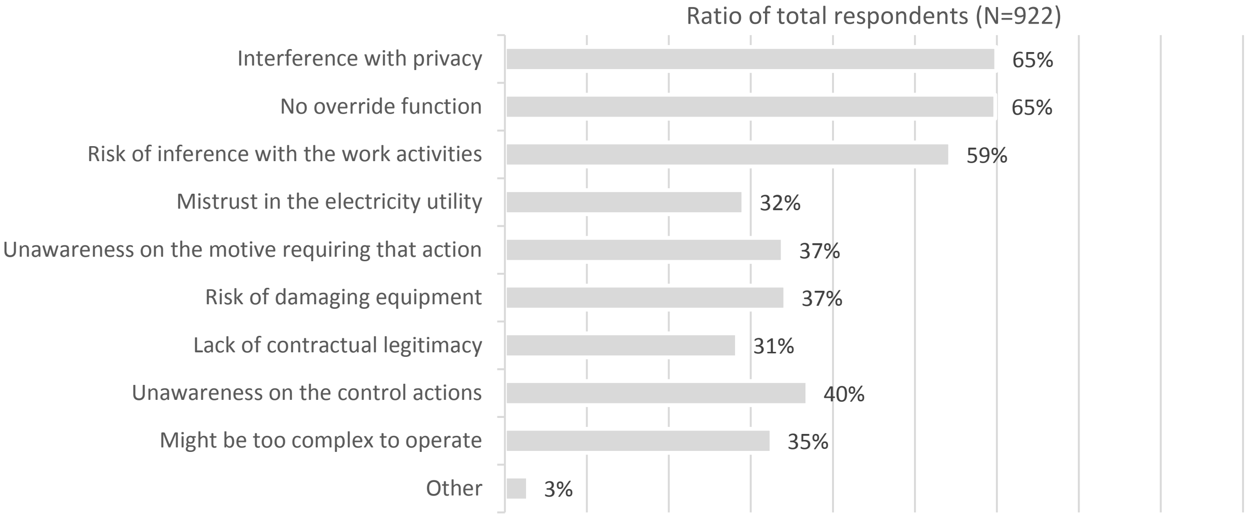


Figure 4.11 Reasons to not follow the recommendations from the electricity utility and manually control the appliances.

Consistent with the previous results, it is evident that office end-users were not ready to completely accept whichever control and they wanted to always be able to override the control to adapt it to personal preferences and privacy needs. It is interesting to see that environmental advantages were considered more important than electricity bill savings for both cases of remote control and manual control.

To understand the respondents' preferences to accept a flexible energy usage, a list of motivating information was provided using a Likert scale with from '1-not motivated at all' to '5-really motivated' as choices. The results are shown in Figure 4.12. The top three preferences were 'seeing how much money you are saving' (45.8% stated preference '5-really motivated'), 'seeing how much you are minimizing your electricity usage' (45.3% stated preference '5-really motivated') and 'seeing how sustainable you are' (38.6% stated preference '5-really motivated'). The option 'seeing how you are doing compared to your colleagues' resulted the least interesting for most of the respondents (37.1% stated preference '1-not motivated at all').

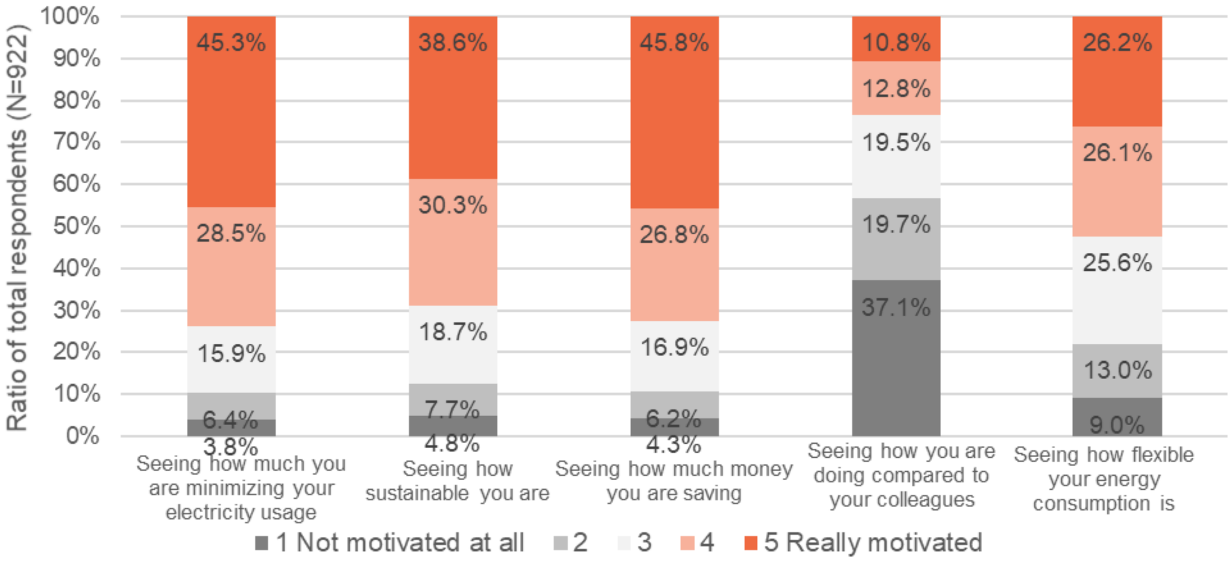


Figure 4.12 List of motivating information to accept flexible energy usage.

A further question was provided to understand which kind of information office end-users would like to see on a display in the office. The top two preferences between the provided options resulted 'the amount of saved energy' (81%) and 'the amount of saved money' (67%), as shown in Figure 4.13.

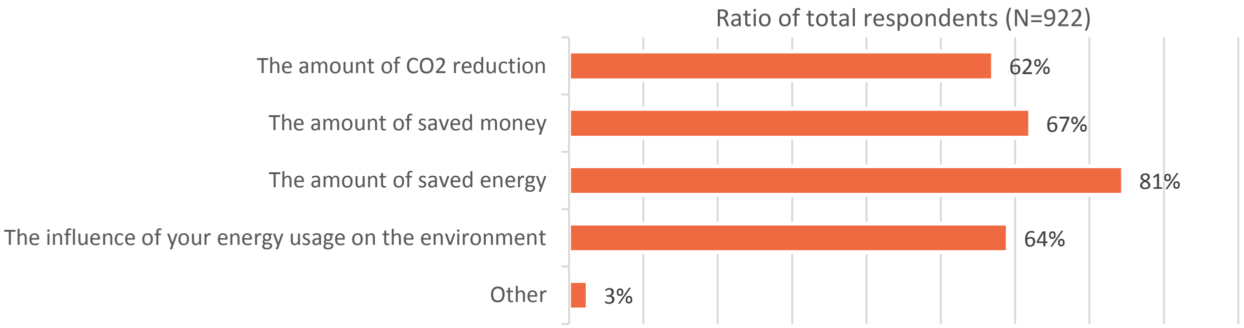


Figure 4.13 List of possible information to see on the display of the office energy monitor.

The last question of the survey was aimed at investigating how the respondents thought that smart grids would influence their work. The 5-point Likert scale from '0-in a bad way' to '5-in a good way' was provided. As shown in Figure 4.14, more than half of the office end-users (51%) expressed that smart grids would have a neutral influence on their work, highlighting that there was not a full awareness of the potential impact of energy flexibility, while a percentage of 12% thought that smart grids would influence their work in a really good way.

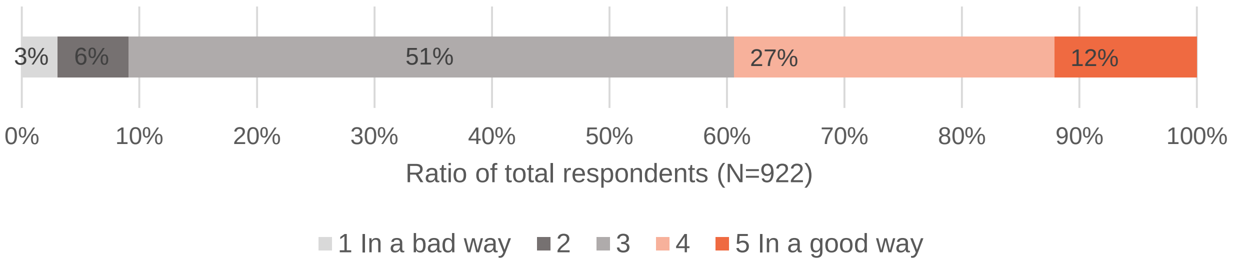


Figure 4.14 Possibility of influence on work activities of smart grids

4.5 Case 3 - Households

4.5.1 Introduction

This study aims to provide a broader perspective on energy flexibility, by surveying a large representative sample of households in the Netherlands. It aimed to understand the influence of individual/household characteristics, dwelling characteristics, household energy consumption, and knowledge and acceptance of smart grid technologies on the willingness of occupants to use smart technologies and change their behaviour when it comes to use of energy. How well building users are prepared to contribute to the energy flexibility of their buildings was assessed. Building user perceptions of smart grids and their readiness to adopt smart technologies were also investigated.

The survey was completed by 835 respondents, of which 785 (94 %) were considered to have provided a genuine response.

4.5.2 Methodology

Questionnaire design

The questionnaire consisted of questions about (1) user perceptions of smart grids, smart technologies, their willingness to use smart technologies and change energy use behaviours, and (2) sociodemographic characteristics and current energy use behaviours.

Firstly, a short description of smart grids was provided, as it was assumed that the concept of smart grids would be unfamiliar to the majority of building users. This description was about the concept and working principle of smart grids, and some of the possible influences on the daily lives for the users. Next, the survey participants were asked to answer questions about their perception, willingness, and motivation to use smart grid products and services. In these questions, a 5-point Likert scale was used. Finally, the participants were asked for respondent and household characteristics, dwelling characteristics, and current energy usage, including energy bill information and heating habits.

Survey and response

The questionnaire was translated into Dutch and completed by ten Dutch locals with different educational backgrounds. The feedback from them was implemented so that the questionnaire would be easily understood by all test participants. The final version of the questionnaire was used for a large scale survey in July and August 2016 through a professional online survey company. The survey was restricted to subjects who were fully or partly responsible for paying their household energy bills, so the population segment younger than 20 years old was excluded from this survey. The questionnaire link was sent to contacts in the company's database selected by the following interlocked stratification, which was intended to be representative of the Dutch population: gender (female: 50% and male: 50%), age (20–29 years old: 19%, 30–44 years old: 25%, 45–59 years old: 27%, and 60 years old and above: 29%), and education level (low: 23%, middle: 48%, and high: 29 %). The online survey was closed when 835 questionnaires had been completed.

Data analysis

The time it took to answer the questionnaire was used as a filter to select effective respondents. This filter is the same as used in a comparable survey by (Broman Toft et al., 2014). In this study, respondents who completed the survey in less than 5 minutes were excluded from the analysis as they were assumed to have answered arbitrarily. As a result, 785 respondents were classed as reliable and used in the data analysis. For these 785 effective respondents, the average time spent answering the questionnaire was 16 minutes.

Descriptive analysis was performed to uncover user perceptions of smart grids and their impact on the daily lives of users. Statistical analysis was conducted using the statistical analysis software SPSS[1] to analyze user readiness for energy flexible buildings. The aim was to understand the influence of individual/household characteristics, dwelling characteristics, household energy consumption, and knowledge and acceptance of smart grid technologies on the willingness of occupants to use smart technologies and change their energy use behaviour. Therefore, several regression analyses were performed on the dependent variables as measures of willingness to use smart technologies, postpone home appliance start times, turn off the heating or air-conditioning for a short time, and reduce the heating temperature setting. The willingness to use smart technologies and the willingness to postpone the start times of home appliances were analyzed using linear regressions. Their willingness to turn off heating or air-conditioning for a short time and their willingness to reduce the heating temperature settings were examined using ordinal regressions. The regression analysis type was chosen according to the type of the dependent variables. In these analyses, the dependent variable for each estimation was also used as an independent variable in other analyses. In this way, information overlap between the analyses was avoided and any relations between each measure of the respondents' acceptance of smart grids could be determined.

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[1] https://www.ibm.com/analytics/spss-statistics-software

4.5.3 Results and discussion

Familiarity with smart grids and smart technologies

After providing an introduction to smart grids and their possible influence on the daily lives of the users, the respondents were asked about their awareness of smart grids prior to the survey. Five options were presented, from “never heard of it” to “know a lot about the concept.” As shown in Figure 4.15, more than 60% of the respondents were not previously aware of the concept. The rest of the respondents were aware of the concept, but only a small number of them (less than 5%) stated that they understood the concept and its consequences.

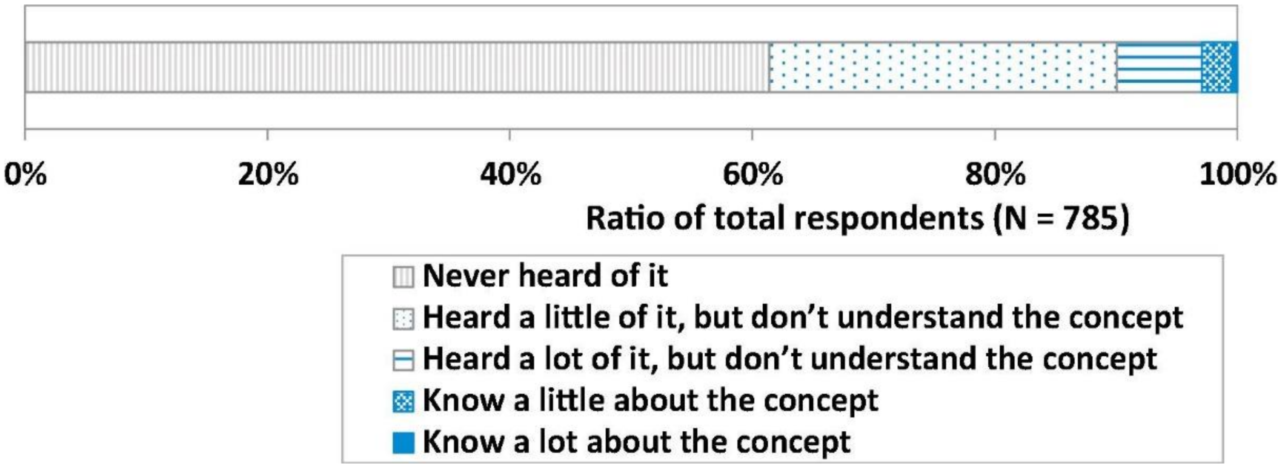

Figure 4.15 Familiarity with smart grids.

When familiarity across age groups is considered (as shown in Figure 4.16), it was found that 48% of young people (20–29 years old) were already aware of smart grids. The highest degree of awareness was found within the age category 20 to 29, followed by 30 to 44, 45 to 59, and lastly 60 and above. This may indicate that younger people are more aware of smart grids than older people.

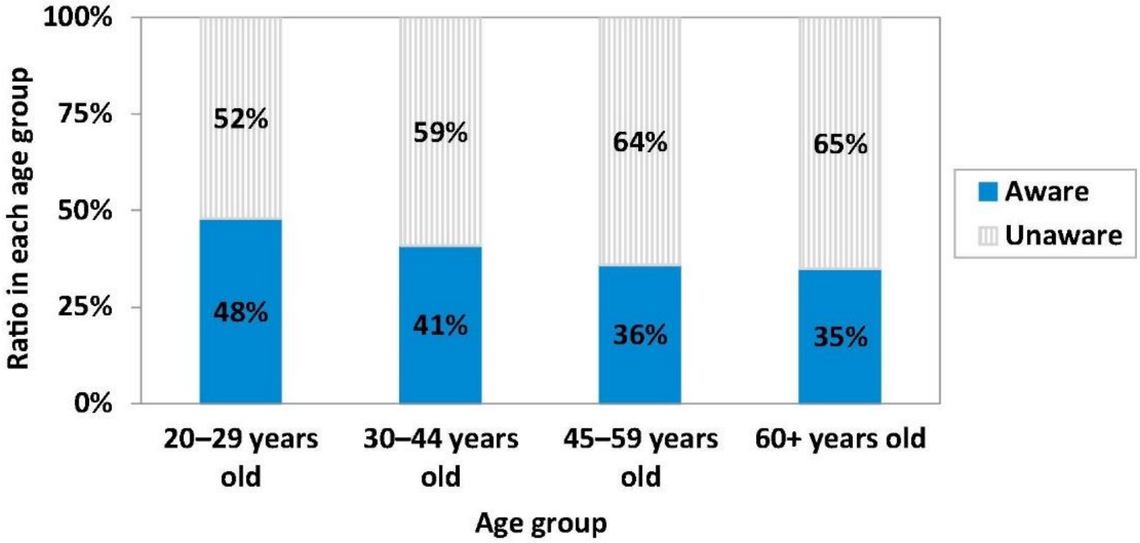

Figure 4.16 Awareness of smart grids by age category.

Awareness about each smart technology is shown in Figure 4.17. The options for answering this question ranged from “never heard of it” to “I own one.” Although the awareness about each individual product or service was different, on average, more than half of the respondents knew about smart technologies, which was higher than their awareness of smart grids. The reason for the discrepancy might be that products or services are closer to the daily lives of the respondents than power grids. Solar panels (PV), smart meters, and electric vehicles were the top three products that respondents knew about prior to the survey.

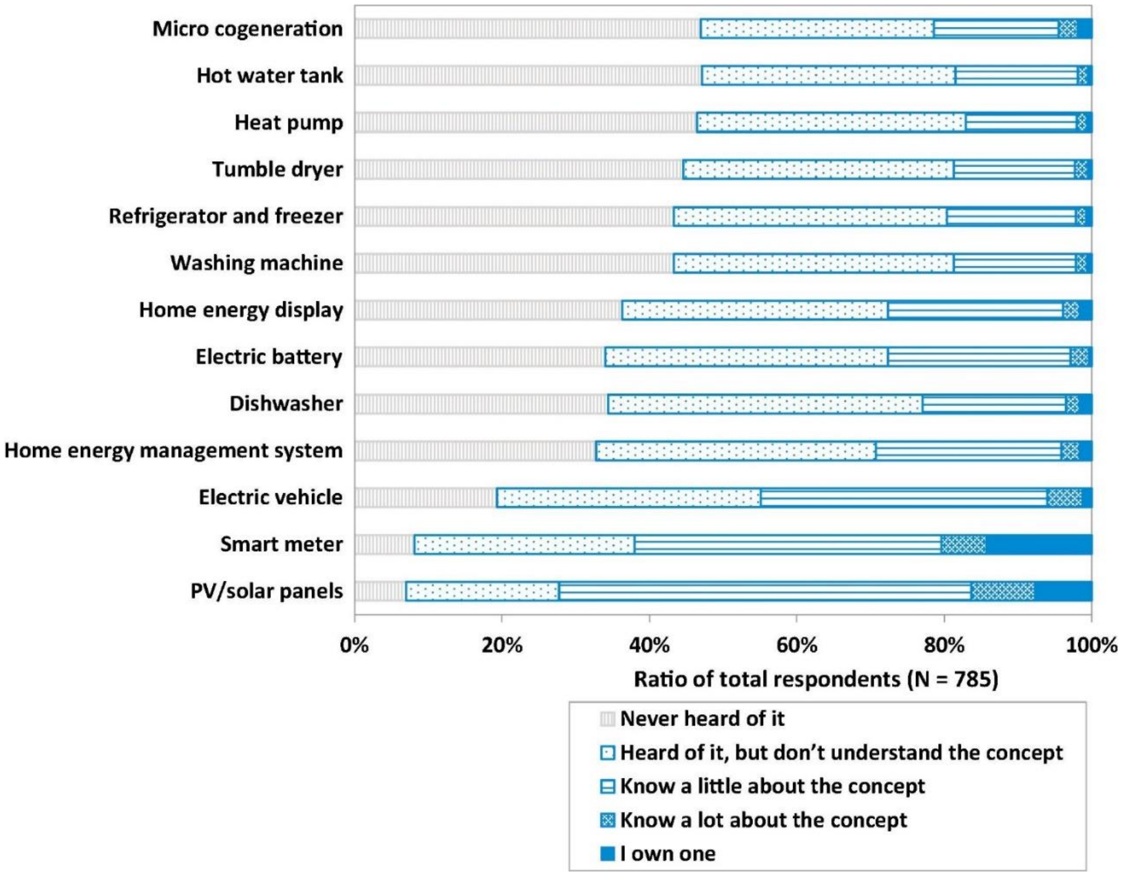

Figure 4.17 Familiarity with smart technologies.

Potential flexible building users

The statistical analysis shows that some individual, household, and dwelling characteristics, such as age, gender, house type, house size, household size, and income, influence the willingness to adopt some smart grid technologies. However, these variables were not found to have a significant impact on the overall willingness. These results, therefore, do not allow for generalized conclusions to be drawn regarding the identification of population groups in terms of their readiness for energy flexible buildings. The reason could be that smart grids and their related technologies are in general unfamiliar to the population. This is different from other studies of user perception of energy conservation in dwellings, such as Hara et al. (2015). This study is based on a large-scale survey in Japan and found that family size, age, household income and a number of air conditioners are determinant factors of the respondents’ perception of household energy conservation. This could possibly be explained by building energy conservation being a familiar topic to the residents while smart grids and energy flexible buildings are not.

Furthermore, this study found that household energy attributes, such as the average energy bill, the impact of the energy bill on the family budget, and their habitual usage of heating systems all influenced their willingness to adopt smart grid technologies. These influences were more noticeable for willingness to postpone the start of home appliances and to use smart technologies. In addition, increasing familiarity with smart grid technology also increased willingness to change energy use behaviour, as expected.

When considering attitudinal variables, it can be seen that there was an interdependency between the variables that define willingness to adopt smart grid technology (as illustrated in Figure 4.18):

- People who are willing to postpone the start of home appliances are also willing to use smart technologies and vice versa.
- People who are willing to use smart technologies are also willing to turn off heating or air-conditioning for a short time and to reduce the heating temperature setting.
- People who are willing to turn off heating or air-conditioning for a short time are also willing to reduce the set point for heating and vice versa.

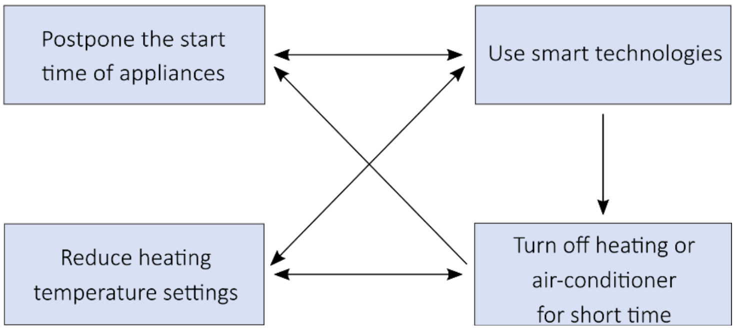

Figure 4.18 Interdependencies found among four measures of willingness to adopt smart technologies.

According to these results, potential users of flexible buildings can be defined as those who are willing to use smart technologies and change their energy use behaviours, including postponing the start of appliances, turning off heating or cooling for a short time, and reducing the heating temperature setting. To estimate the number of potential flexible building users, it was assumed that flexible building users are:

- Willing to postpone the start time of half or more of their appliances,
- Willing to use half or more of the smart technologies listed in the questionnaire,
- Willing to turn off their heating or air-conditioning, and
- Willing to reduce the heating temperature setting.

Based on this assumption, results suggest that 11% of the respondents were potential users of flexible buildings. Although this value is somewhat arbitrary and dependent on the above criteria, it gives a rough understanding of the readiness of residents of energy flexible buildings.

4.6 Conclusions

The results of case 1 - Occupants in energy flexible campus buildings, show that students do not agree to have a frequent change of the indoor climate. They believe that frequent changes in indoor comfort in the classrooms can influence the teaching and learning performance. Meanwhile, students can accept frequent changes of the indoor comfort in hallways and canteens, rather than the rest of the campus buildings, e.g. classrooms, auditorium, labs, group rooms, and offices. Students can be motivated and accept a university’s energy flexibility plan if it is part of the university green and environmental strategy.

The analysis for case 2 reveals that the use of renewable energy instead of fossil fuels in office buildings is recognized as a very important action. Conversely, the knowledge of smart grids is shown to be unfamiliar to more than half of the respondents prior to the questionnaire. In the office building, the occupants state that the most suitable smart appliances accepted to be remotely controlled are the air conditioning and the heating system. In both cases of remote control and manual control of smart appliances, the main motivating conditions resulted in the possibility to override at any time the control in order to not compromise the privacy and environmental advantages. The main motivating factors to accept a flexible energy usage are the possibility to see how much the electricity usage is minimized, the amount of saved money and the most effective information to be displayed on a monitor in the office is the amount of saved energy. Regarding the possible influence of smart grids on office work, more than half of the office end-users express a neutral position, probably due to their unawareness of the smart grid functioning principles and possible effects.

The results obtained from the case 3 - Households, provide important insights for energy policy makers and energy companies to create policies and strategies towards the development of future power grids and to encouraging building users to be more flexible. For example, in order to encourage people to adopt smart grid technology, awareness of smart grids must be increased. Awareness should not be limited to young people but should be disseminated to the entire population. The adoption of smart grids can also be increased through financial incentives by focusing on residents with mid-level energy bills. It appears that people who are willing to use smart technologies are also willing to change their energy use behaviour and can thus be defined as flexible. In order to unlock the energy flexibility of buildings, the adoption of smart technologies should be encouraged by providing incentives such as financial rewards.

5. Energy suppliers in Energy Flexible Buildings

5.1 Introduction

Energy suppliers have traditionally assumed the role of maintaining the balance between supply and demand. This responsibility makes them important stakeholders in future smart grids and energy systems. As the number of potentially flexible consumers increases, it is up the energy suppliers to develop business strategies that can utilize such flexible loads, to not only reduce the costs of maintaining and operating their energy distribution- and generation infrastructure, but also reduce their impact on the environment. Flexible consumers may be a valuable asset for addressing the challenges associated with an energy supply characterized by a large share of intermittent production from renewable energy sources.

A large share of the energy that is consumed in buildings is supplied through electricity distribution grids or, in some colder climates, through district heating networks. Therefore, the following sections describe the potential of utilizing flexible consumers from the perspective of both district and electricity heating suppliers.

This section includes two cases to discuss the roles and participation of district heating suppliers in the energy flexible buildings:

- Case 1 - Demand Response (DR) opportunities and challenges for district heating suppliers in Denmark.
- Case 2 - Stakeholder's perception and motivation on smart district heating grids using energy flexible buildings.

5.2 Background

Several studies have suggested that energy suppliers and distributors may benefit from having DR at their disposal in a variety of operational conditions and during the initial sizing of infrastructure. As the penetration of renewable production in the electricity sector increases, researchers have suggested that increased interaction between the electricity and district heating sectors could have synergetic effects (Lund et al., 2012, Lund et al., 2014). One of these synergies is the ability to mitigate the curtailment of renewable energy production by using excess electricity to supply district heating systems with heat from largescale heat pumps. Increased utilization of district heating has been suggested as one of the approaches to decarbonizing the European energy system (Connolly et al., 2014). Therefore, the opportunities associated with energy flexible buildings are not only relevant in the context of smart grids and thereby the electricity sector but are also relevant for district heating systems as well.

Table 5.1 Summary of data collection and results.

Purpose:	Types of Buildings	Methodology	Targeted aspect	Result highlights
District heating suppliers	All buildings connected to district heating networks	Research collaboration Interviews Literature review Analysis of production data	Challenges in district heating operation Opportunities for DR initiatives	• District heating suppliers consider flexible consumers a potentially valuable asset – but only if DR participation can be ensured through contractual means. • Energy flexible buildings compete with the less complex solution of centralized storage tanks. • There is currently no straightforward way of determining the economic incentive that could be provided to consumers. • There is a large potential for reducing the required heat generation capacity of the network by reducing the level of consumption during a relatively low number of hours: Removing 50 hours per year with the highest consumption reduces the required capacity by 14-17 %. • Reducing necessary pipe dimensions or supply temperature in order to reduce heat losses in the distribution network also hold significant potential.
District heating suppliers' activities and opinions	All types of buildings within district heating networks	Questionnaire	Smart operation of district heating grids Economic perspectives/ business and tariff models Drivers and barriers of using energy flexibility	• The relevance of smart district heating technologies and know-how is higher than expected • District heating suppliers believe that energy flexible buildings are important and allow for shifting heating peaks or for decentralized storage of heat from the grid, and for the control optimization for using the flexibility • There seems to be a relevant market for intelligent district heating concepts • Renewable energy use for district heating grids is of high importance • Cost, incentive and regulation related drivers and barriers are more important than data privacy or comfort issues

5.2.1 District heating suppliers and energy flexibility

District heating (DH) is already an additional source of flexibility with some magnitude in several countries, particularly in Denmark, and has a large potential. In the frame of Flex4RES project (Daniel Møller Sneum, 2016), national surveys of the regulation framework for DH through review and consultation with key stakeholders in seven Nordic and Baltic countries (Iceland is not included) were conducted. The objective was to identify drivers and barriers for utilizing DH as a source of flexibility for the power market.

"System intelligence" in hybrid networks, combining district heating with other energy networks, is considered to be of great importance in a cross-domain view that coordinates and optimizes storage and transport functions as well as intersectoral load shifting. The economics of interconnection, technical flexibility, development towards an energy information network and intersectoral interoperability, are also important aspects of a hybrid network (Appelrath; et al., 2012).

District heating systems cannot be easily adapted to demand. Additional buildings can only be connected to a district heating grid if the existing distribution pipe system is able to deliver more energy, or if other already connected buildings reduce their heat demand. For instance, some Austrian district heating grid supply and utility companies have introduced hot water storage tanks in a few buildings in order to avoid heat shortage. In this case, the heat meters count heat only after the hot water tank, and losses are paid for by the utility company and not the private heat consumer. This is called a distributed storage system.

Challenges in district heating systems:

- Additional buildings are to be connected (expansion): existing pipes cannot deliver enough energy. The system is undersized.
- Thermal renovation of buildings: The energy demand of buildings is reduced. Also, the temperature level of consumption is reduced, however, it might then happen that return water is very hot. The system is oversized.

Solutions to these issues include: the combination of network expansion and thermal renovation; the installation of heat storage tanks in buildings for load shifting; and the use of energy flexible buildings that can store heat to shift and smooth loads. For example, if additional buildings are to be connected, but the locally available flow rate is too low in the peak time (i.e. in the morning), then storage can be used to overcome this. Just like a hot water storage tank, an energy flexible building can store heat and thus reduce heat demand at a given time.

Heat consumers in Austria normally pay for:

- Available delivery rate/connected power (in kW)

- Delivered heat (in kWh)

They pay for delivered heat at a previously defined temperature, which is normally high (~90°C), because the utility company has to deliver heat at a temperature level that allows even the last consumer in the line to reach 60°C in order to avoid Legionella growth.

In general, district heating systems in Austria do not use so much renewable energy compared to the electricity grids. They are mostly fed by natural gas (around 35% - typical in large towns) and bio-based fuels (45% - typical in small towns). The generation is limited by the total available power from the heat plants, which is however normally quite high. The differences to electrical grids are summarized in Table 5.2.

The results of a study by (Knudsen and Petersen, 2016), indicate that flexible consumers can utilize the thermal mass inherent in their building to shift consumption to periods with a higher share of renewable production from wind turbines. This suggests that flexible consumers connected to the electricity grid could be used to absorb excess energy production from renewables by storing it in the thermal mass of their buildings, thereby avoiding curtailment of production while reducing their energy demand in the following periods. Multiple studies have similarly indicated that the daily peak consumption in a building may be reduced by using appropriately designed cost signals in model predictive control schemes, to optimize space heating operation of residential buildings (Oldewurtel et al., 2010, Reynders et al., 2013, Pedersen et al., 2017). Although individual peaks are usually not a concern for energy suppliers, the energy flexibility identified in these studies could easily be devoted to reducing peaks in the aggregated consumption profile.

In terms of district heating networks, Brange et al. investigated in two studies the causes of bottlenecks in Swedish district heating systems and evaluated several different approaches to address them (Brange, et al., 2017). Expansion of existing networks was found to be the most common cause of congestion issues (51%), while densification within areas already supplied by district heating accounted for 25% of the identified bottlenecks. The authors found that the most common approaches used to address bottlenecks were increasing the pipe area by installing larger or additional pipes, increasing the supply temperature or upgrading pumping stations.

In addition to the currently used methods described above, the authors investigated a demand response initiative which involved consumers accepting a reduced supply during peak hours. In a case study, demand response was found to be among the cheapest of the evaluated approaches to address bottlenecks – partly due to the relatively low investment costs associated with establishing a demand response. The authors, however, argue that the price associated with implementing DR in buildings would depend on the number of consumers that would be required to participate in addressing the bottleneck. Dominkovic et al. investigated the potential of utilizing energy flexible buildings for demand response in district heating systems through a system-wide optimization (Dominković et al., 2018). The authors found that the economic savings achievable through demand response ranged from 0.7% – 4.6% of the total operational costs and that the profitable investment in each building was up to €261 per house.

Table 5.2 Comparison of Power Grids and District Heating.

	Power Grid	District Heating
Storage potential in distribution	Almost zero	High
Reaction (time)	Instantaneous	Slow
Infrastructure cost	Middle	High
Distribution losses	~6 %	~Up to 30 %
Energy Flow	Voltage, current	Temperature, volume flow (pressure)
Energy Flow dependence of ducts defined	By diameter, material	By diameter, material reliability (age)
Variability of Energy Flow	High	Low
Peak requirement	In the evening	In the morning
Restriction of total delivered power by	Generation limits	Distribution limits
Storage	The pumped storage hydropower plant	The system itself, additional use of centralized or decentralized water storage tanks

5.2.2 *Electricity suppliers and energy flexibility*

The fact that there has not been any growth in the share of renewables in the power sector over the last ten years, shows that there are still problems with integrating enough renewable energy in the power grid at a competitive price (BP, 2018). The total share of fossil fuels in the world's primary energy demand is still the same as 25 years ago (IEA, 2018). To meet the growing electricity, need in a sustainable way, the share of renewable energy in the global power mix must increase. Solar and wind power is expected to receive 75% of the new support for renewable electricity generation towards 2040. Due to their intermittent nature, energy flexibility is increasingly important (IEA, 2018). Globally, there is forecast to be a 30 % rise in energy demand in buildings by 2040, according to the International Energy Agency's (IEA's) main scenario (OECD/IEA, 2016). Buildings are expected to remain the largest consumer of electricity and the largest growth area. In this context, energy flexible buildings are, therefore, especially important. The electricity demand in buildings is expected to grow by 60% on average until 2040. The forecast growth is mainly attributed to developing countries, who are expected to have a 90% growth in their electricity demand by 2040.

Consumption by electric appliances alone accounts for more than 20% of the world's electricity demand, more than the heating and cooling demand combined. Appliances were the single factor that caused the largest growth in energy use in buildings between 2000 and 2017 (IEA, 2018). Therefore, it is important for electricity suppliers to forecast load from appliances accurately in order to plan their generation requirements.

Better demand side management has several advantages, both for the customers and energy utilities (Le Dréau and Heiselberg, 2016):

- Reduction in transmission losses, by using electricity from local PV generation on-site instead of feeding it into the grid.
- Reduction in grid stress which increases the reliability of grid operation and reduces or delays the need for investments into the grid infrastructure.
- Cost savings for customers by consuming electricity during times when the marginal cost of power generation is minimal.
- Possibilities to increase or decrease the load at short notice in the case of unforeseen events.

PV generation has increased 10 times from 0.2% in 2000 to 2% today (IEA, 2018). In 2040, the global generation is likely to reach 10%, due to falling costs and political support. The majority is utility scale, which creates a challenge for the utility companies to increase energy flexibility to integrate more PV in the electricity mix.

world added more capacity from solar PV than from any other type of power generating technology (REN21, 2018). PV added more network capacity than nuclear power, coal, and natural gas combined, and twice as much as wind power (REN21, 2018). New solar PV is now outcompeting new coal in most places (IEA, 2018). According to the IEA's latest Sustainable Development scenario, the global Photovoltaic (PV) capacity should rise to more than 4200 GW by 2040 (IEA, 2018). China and India contribute to 48 % of the increase in the global primary energy demand from 2017-2040. The levelized cost of electricity (LCOE), which is a metric to combine the average cost of electricity over the lifetime of a project, has for PV decreased 65 % over the last five years (IEA, 2018). LCOE is lowest in China and India due to the low capital cost and good solar resources. The PV module prices dropped at an average of 20.9% per year from 1980 to 2014 and the price continues to fall towards the critical cost.

5.3 Case 1 – DR opportunities and challenges for district heating suppliers in Denmark

5.3.1 Introduction

A fundamental difference between electricity grids and DH networks is the fact that the latter, due to distribution losses, are confined to regions characterized by a significant demand. Electricity grids, on the other hand, span entire nations and form, through interconnections between nations, an international electricity grid. The limited spatial extent of DH networks means that there are often significant differences between them – both in terms of the portfolios of heat generation units and in the challenges related to maintaining an efficient distribution grid. Therefore, the perspective of one district heating company may deviate significantly from other suppliers of DH. The details in this section are based on an on-going research collaboration between Aarhus University and the district heating and waste incineration company 'AffaldVarme Aarhus' (AVA). AVA supplies district heating to 350,000 customers within Aarhus and in the surrounding suburbs and towns, and is thereby one of the largest DH supply companies in Denmark.

The DH customers in Aarhus have undergone a transition from manually reporting their consumption on an annual basis, to automatically reporting consumption through smart meters on an hourly basis. Although the main reason for investing in these smart meters was for billing purposes, AVA is interested in putting the hourly consumption data generated by the smart meters into use. AVA have therefore, through participation in several research projects, started to investigate the potentials related to demand response and energy flexible buildings. Current collaborations involve the Local Heating Concepts project funded by EUDP[2] (Project number 64017-0019), in which one of the research objectives is to evaluate the potential of flexible consumers in district heating networks. Previous research projects have focused on using the data to calibrate hierarchical archetype building energy models. These models may be used to inform the decision-making process during the sizing of components for new areas that are to be supplied by district heating, but also to evaluate the potential impact of future energy conservation measures such as energy retrofitting.

5.3.2 Methodology

A summary of important points brought forward by AVA is presented in the next section 5.3.3. The details provided were obtained partially through semi-structured interviews and

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[2] Det Energiteknologiske Udviklings- og Demonstrationsprogram

correspondences with engineers employed at AVA, and partially through project meetings and general discussions. As demand response is currently not being actively pursued by the district heating supplier, the purpose of these interviews was to identify challenges in the daily operation of the DH network which could be addressed through utilization of the flexible demand associated with energy flexible buildings.

Aggregated production and consumption data for the years 2015-2017 were made available. The data were analyzed to estimate whether the temporal distribution of the demand and the weather conditions during these hours of peak consumption were aligned with the flexibility capabilities of buildings.

5.3.3 Results and discussion

The following sections describe the challenges and opportunities of district heating suppliers which can potentially be addressed/achieved through utilization of flexible consumers.

Challenges

Changes in the demand for district heating is one of the key challenges in operating district-heating systems. The societal and economic expenses associated with establishing or modifying district heating networks are extremely high, in part due to the material costs and a large number of man-hours that go into putting pipes in to the ground, but also due to the traffic-related issues that are associated with such intrusive construction work occurring within populated areas. Network expansion and city densification are the two most frequent causes of changing demand and bottlenecks (Brange, et al., 2017).

Network expansions

Whenever previously unpopulated areas are converted to residential or commercial areas due to expanding city limits, district heating companies are faced with the challenge of predicting the future consumption level of the newly supplied area. The sizing of the new parts of the network is based on the predicted demand during an empirically based peak consumption scenario. Oversized district heating pipes result in an undesirable increase in heat losses in the network as well as an unnecessarily large material cost, while undersized pipes may lead to congestion issues and dissatisfied customers.

Several countries rely on strategic planning/zoning when establishing district heating networks (Euroheat and Power, 2011). The Danish regulations require buildings built within areas supplied with district heating to be connected to the network (The Danish Energy Agency, 2017). This practice is used both to ensure a sufficient economical foundation for the typically large up-front investments that are associated with expanding district heating networks, but also to provide district heating companies with relatively certain estimates of the future consumption level in the area, such that the dimensions of pipes and other relevant infrastructure components may be optimized. It has recently been debated whether this requirement should be removed in the future in Denmark.

The association of Danish district heating companies, Dansk Fjernvarme, consider removal of the so-called ‘obligation to connect’[3] to be a significant problem for continued growth in heat networks. The association argues that the risk associated with the increased uncertainty related to the size of the consumer-base would remove the incentive for DH suppliers to extend existing networks, thereby inhibiting the district heating sector which is considered a key element of the transition to renewable energy. AVA consider utilization of flexible consumers to be one of the possible approaches to reduce the impact of this increased uncertainty. This is because demand response initiatives could be used to lower the issues of lacking capacity during the relatively few hours each year with extreme demand, thereby allowing for a sizing of components that is optimal during the majority of the heating season. However, an important point made by the DH supplier is that the contribution from flexible consumers would only be included in DH network sizing if participation could be guaranteed – e.g. through contractual agreements. DR schemes based on voluntary participation are difficult to incorporate in network sizing due to the uncertainty related to future participation rates.

City densification

Densification refers to scenarios where the demand in a given area already supplied with district heating is increasing, e.g. due to detached housing being replaced by medium or high-rise residential buildings. In contrast to network expansions, densification scenarios often involve existing pipelines, which may not yet have reached the end of their technical lifetime. The district heating company consider it a possibility that utilization of energy flexible buildings can allow for the investment in new and larger pipes to be postponed until the existing infrastructure has reached the end of its technical service life. If this can be achieved, flexible demand holds significant economic value for the district heating supplier. However, as already stated, a prerequisite for incorporating flexible consumers in the planning of future infrastructure upgrades is that the district heating company, through contractual means, can ensure a sufficient flexible demand.

Opportunities

In addition to the challenges related to operating district heating networks, it is also relevant to identify whether the utilization of flexible consumers constitutes opportunities for further optimizing the daily operation. Three opportunities relevant to AVA were identified:

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[3] https://ens.dk/sites/ens.dk/files/Globalcooperation/regulation_and_planning_of_district_heating_in_denmark.pdf

Optimization of the generation portfolio

The generation portfolio that supplies a district heating network with heat can be diverse and include both boiler plants, CHP plants, electrical boilers, and heat pumps. On top of these units, district heating is often also produced from renewable production (e.g. solar thermal) and utilization of surplus heat from industrial processes. One of the potential benefits of utilization of energy flexible buildings, is that the activation and operation of a portfolio of generation assets can be further optimized (Wernstedt et al., 2007). Examples of optimized daily operation given by Wernstedt et al. (2007) includes running production units in their most efficient states, avoiding the start of cold plants to follow daily fluctuations in demand, reducing the use of expensive oil-fired boilers, and optimizing the profits of CHP plants by considering electricity prices in the production planning. In the context of the latter, Kärkkäinen et al. (2004) provide the example of the heat delivery from a CHP plant in Mannheim, where the costs associated with heat are proportional to the loss in electricity production. The authors state that the reduction in electricity output per MJ/s heat from the Mannheim CHP-plant increases with the heat load.

The conditions that make flexible consumers relevant in the optimization of daily production are dependent on a variety of factors related to both the district heating network and the portfolio of generation units. From the perspective of the AVA, the additional heat generated in a backpressure CHP plant that is running at maximum capacity due to high electricity prices could in principle be stored in the thermal mass of buildings. However, the district heating company lean towards the simpler option of relying on large-scale thermal accumulation tanks to provide such flexibility. While AVA does not consider utilization of flexible demand directly in production planning to be feasible due to the complexity involved, the DH supplier could see the potential benefit of using flexible demand to avoid penalties from the electricity markets if the original production plan cannot be realized.

Unstable distribution network

The district heating company also see energy flexible buildings as a possible means of reducing the supply temperature in the grid. In the event of the supply-temperature in the DH distribution network becoming too low (e.g. due to colder-than-expected weather), unstable operation of the distribution network may arise due to the flowrates at the consumer-end increasing in an attempt to make up for the lower supply temperature. This results in an increased loss of pressure in the system that may reduce the pressure in certain parts of the DH network and essentially cut off entire neighbourhoods from the supply. The thermostatic valves in the now unsupplied neighbourhoods also open due to room temperatures in the supplied buildings beginning to drop. Limitations related to the maximum pressure in the network mean that increasing the pressure at central pumping stations to counteract the increased pressure losses may not always be possible. Therefore, a cascade event can occur, where neighbourhoods have to be taken off the grid to ensure stability in the remaining parts of the network. The supply to the affected areas is then re-established one-by-one to ensure that the high initial load associated with reheating the affected buildings do not coincide – a procedure that can take upwards of 8 hours. Due to the significant consumer discomfort associated with a loss of supply, current operating strategies incorporate a significant buffer in the supply temperature to reduce the risk of such an event.

The increased control of the heating load in energy flexible buildings (due to more advanced technical infrastructure) may make them valuable assets in the task of ensuring that such events do not develop, e.g. by containing consumption levels within feasible limits regardless of room temperatures in times of need. This would allow district heating companies to reduce the temperature in the distribution network and thereby the reduce heat losses.

Capacity Reductions

Using energy flexible buildings to reduce the production capacity in the system is considered to be one of the use-cases with the highest potential for generating savings. Figure 5.1 shows the duration curves for three consecutive years. The steep drop in capacity seen in the first part of the duration curves associated with each year indicates that the generation capacity in the network is oversized during a significant portion of the year. If consumption in the 50 hours that were characterized by the highest load each year (2015, 2016 and 2017) could be reduced by flexible consumers, the capacity required to meet the maximum demand would be reduced for each of the years by 14.3%, 17.7%, and 16.5%, respectively.

One of the factors that determines whether energy flexible buildings are capable of lowering consumption levels during these critical hours, is how they are distributed in time. If all 50 hours were to happen consecutively, it would be difficult to reduce consumption levels without consumers experiencing a loss of service. On the other hand, if these critical hours tend to be clustered in daily peaks of shorter duration, utilization of energy flexible buildings may be an attractive method for reducing the required capacity in district heating networks. Figure 5.2 presents how the 50 hours with the highest production levels for each of the three years are distributed in terms of the number of consecutive hours in each cluster. For instance, of the 50 hours of maximum consumption in 2017, twelve of them occurred in two six-hour periods.

The data indicate that the majority of critical hours appear in clusters of four or less consecutive hours. Le Dréau and Heidelberg (2016) found that even poorly insulated buildings are capable of shifting space heating consumption over 2-5 hours, while more energy efficient buildings are capable of reducing their consumption for much longer durations without consumers experiencing comfort issues (Le Dréau & Heiselberg, 2016). As such, the distribution of these hours in itself, does not constitute a hindrance for the utilization of the thermal inertia of energy flexible buildings to achieve significant reductions in the required capacity for heat production in the network.

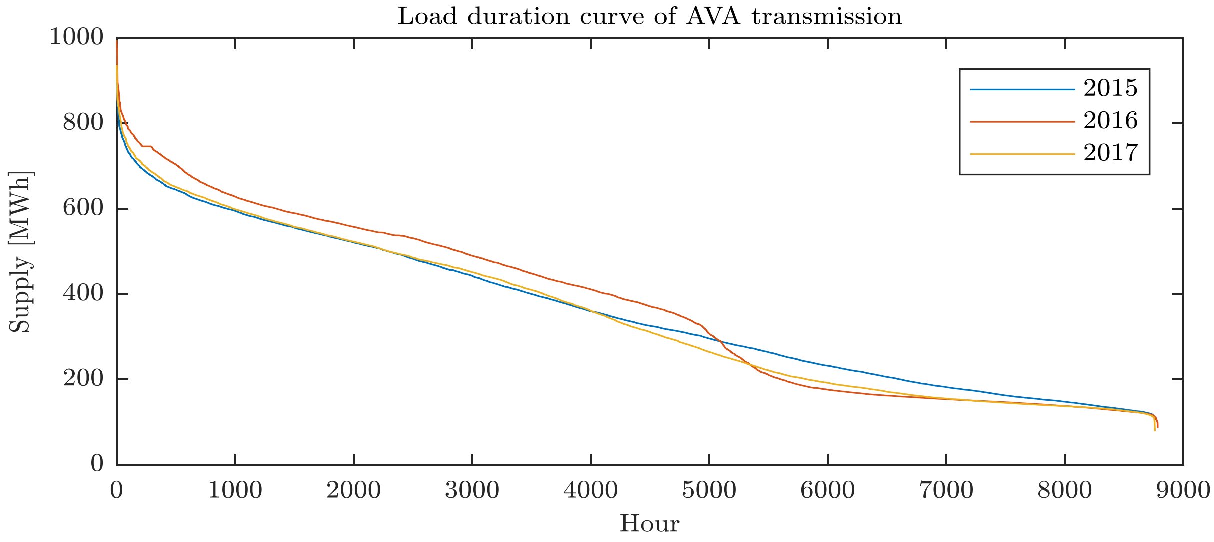


Figure 5.1 Load duration curves for years 2015-2017 for the entire generation portfolio of AVA (District heating production).

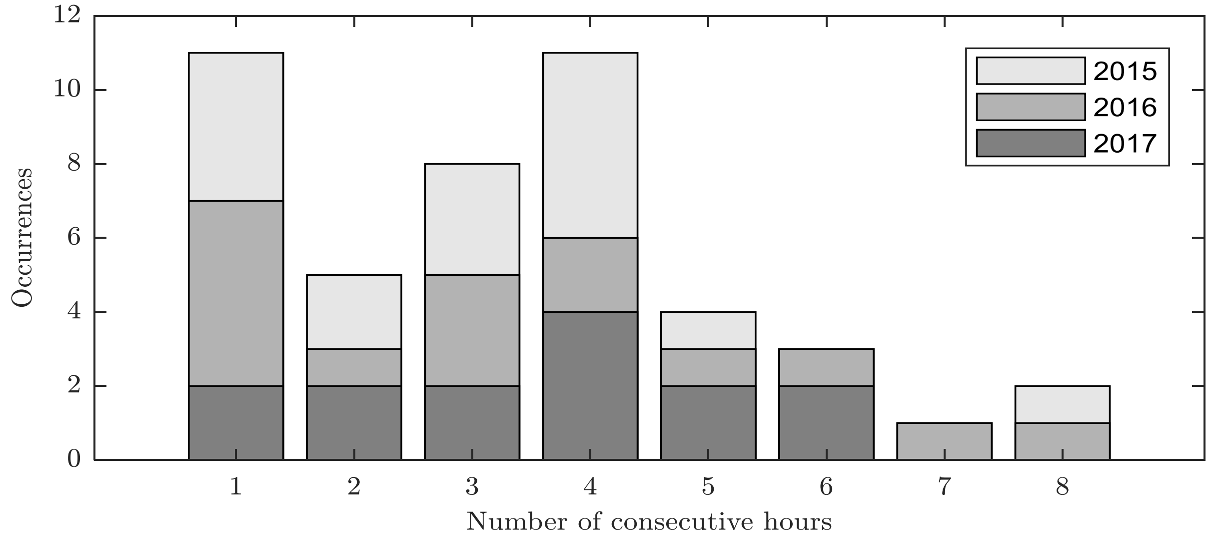


Figure 5.2 Occurrences of clusters with consecutive hours within the 50 hours year with the highest production.

Another important prerequisite for utilization of energy flexible buildings is that the heating systems in the buildings have sufficient heating power capacity available for not only maintaining but also potentially preheating the buildings. In their study, Kontu et al. (2018) found that lacking capacity in the heat delivery systems in buildings was one of the main barriers for load shifting. Figure 5.3 depicts the outdoor temperature conditions in Aarhus during all of the days on which one or several of the 50 hours with the highest consumption each year occurred.

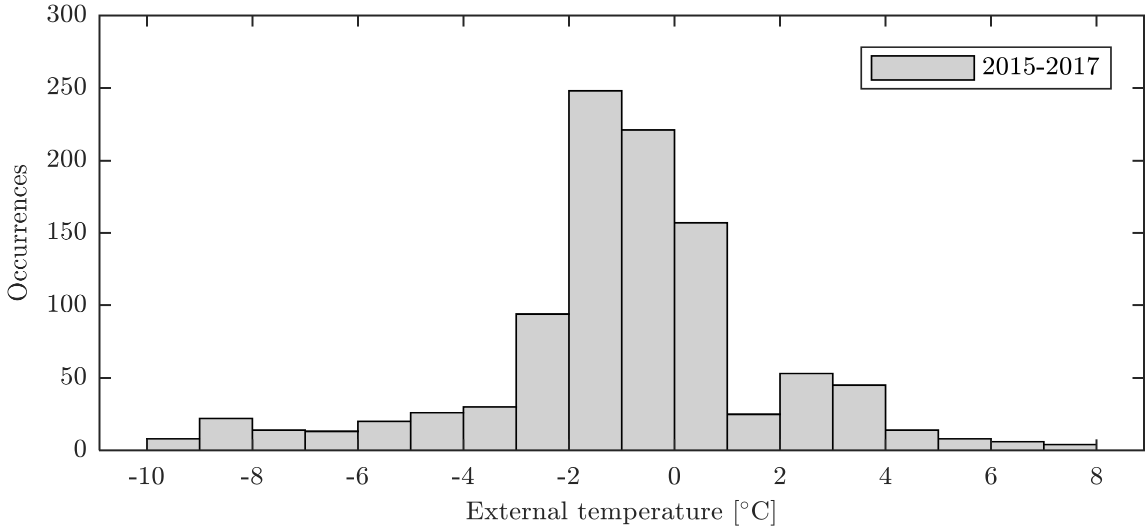


Figure 5.3 Distribution of temperatures during the days in 2015, 2016 and 2017 where one or several of the 50 hours with the most critical load occurred.

The data shows that the temperature conditions on the days that saw peak consumption levels for the majority of time ranged between -3°C to 1°C. Since the heat delivery systems in Danish residential buildings are traditionally designed to ensure comfortable indoor temperatures down to an external temperature of -12°C, it seems likely that a significant number of buildings would have unused capacity in their heating systems and thereby be able to participate in demand response events on these days.

5.4 Case 2 – Stakeholder's perception and motivation on smart district heating grids using energy flexible buildings

5.4.1 Introduction

In Austria a lot of "micro" and district heating grids exist, connecting building clusters of a town or whole villages via district heat. About 26% of all apartments are supplied by heating networks, using fossil fuels (46 % - mainly natural gas), combustible waste (8 %) and increasingly by renewable sources (46 %) (FGW – Fachverband der Gas- und Wärmeversorgungsunternehmungen, 2018). In addition to the few large urban heating networks in Austria (Vienna, Graz, Salzburg, Klagenfurt, Linz, etc.), there are around 2,000 smaller and medium-sized heating networks in Austria (around 600 of them in Styria) (Kommunalkredit Public Consulting, 2014) that primarily use biomass as an energy source, but also use solar thermal energy, and waste heat from biogas plants or industrial processes. In every case, the smaller and medium-sized heating networks play an engaged role in the regional energy transition and the awareness of the rural areas. A lot of these heating grids are organized as co-operatives of forest owners managing the whole heating supply chain of local communities and municipalities – from harvesting wood, via making wooden chips to delivering heat to single buildings.

In relation to the electricity grids, it is not well understood if the district heating suppliers have or use knowledge and know-how on smart grid or intelligent energy system technologies. The possibilities of digitization, predictive and self-learning control, accurate load planning and use of heat networks pose the question of how smart district heating networks can and should be realized in the future. They should increasingly integrate decentralized renewable energy sources, storage facilities and use the energy flexibility of buildings, with the aim of reducing CO_2 emissions while maintaining the same level of customer comfort. To understand how energy flexible buildings can support district heating grids, how energy flexibility in district heating allow for increased use of renewable energy sources, the involvement of decision-makers and stakeholders is necessary.

Therefore, this case explores the motivational factors among heating grid stakeholders and planners and to map the potential for flexibility among their running heating grids. The investigation was carried out in the frame of Austrian IEA EBC Annex 67 tasks and was based on contacts gathered in national projects, including qm Heizwerke (quality management for district networks), UrbanDH_extended, OptSmallGrids and Thermaflex, all carried out by AEE INTEC during recent years and on an ongoing basis.

The questionnaire was developed with the aim to investigate the stakeholders' perception on smart technologies and market potential on smart district heating grids using energy flexibility of buildings in Austria.

5.4.2 Methodology

It was planned to explore the perception of Austrian building users regarding the implementation of energy flexibility measures in real example buildings. Unfortunately, it was not possible to complete these surveys in real buildings. It was however possible to investigate the relationship of district heating grids or heat networks to their "users" – energy flexible buildings in this case. Currently, there is no national stakeholder survey on this topic of energy flexibility of smart district heating in relation to the integration of energy flexible buildings and smart technologies. So, to investigate the stakeholder's perception and motivation on smart district heating grids using energy flexible buildings, a questionnaire was developed, mostly based on a 5-point Likert-type scale. The questionnaire includes four parts based on a literature review (Appelrath; et al., 2012, Li et al., 2017, Ma et al., 2018, Mlecnik, 2018, Korpela et al., 2017, Wärtsilä Finland Corporation, 2015) and internal Annex 67 expert input as shown in Table 5.3. Eighteen questions plus empirical social data have been distributed by this questionnaire to more than 100 stakeholders.

The data collection in Austria was conducted from April to July 2018. The response rate was relatively low with 37 completed questionnaires, but valuable input from the target group could be collected. The surveyed stakeholders were mostly either district heat suppliers or planners, with some respondents from technical municipal staff in charge of the energy management and scientific experts.

Table 5.3 questionnaire content.

Questionnaire section	Contents
Backgrounds	Branch, position in the company Education, gender and age Co-activities
Motivation	Importance of renewable energy sources Challenges/measures in load management
Barriers and concerns	Financial aspects Technological aspects Business aspects Legal and environmental aspects
Economy and policy	Business models Market relevance Policy measures

5.4.3 *Results and discussion*

In the following section, the main results and discussion are presented. Around three-quarters of the responding stakeholders see some or bigger challenges in load management (Figure 5.4)

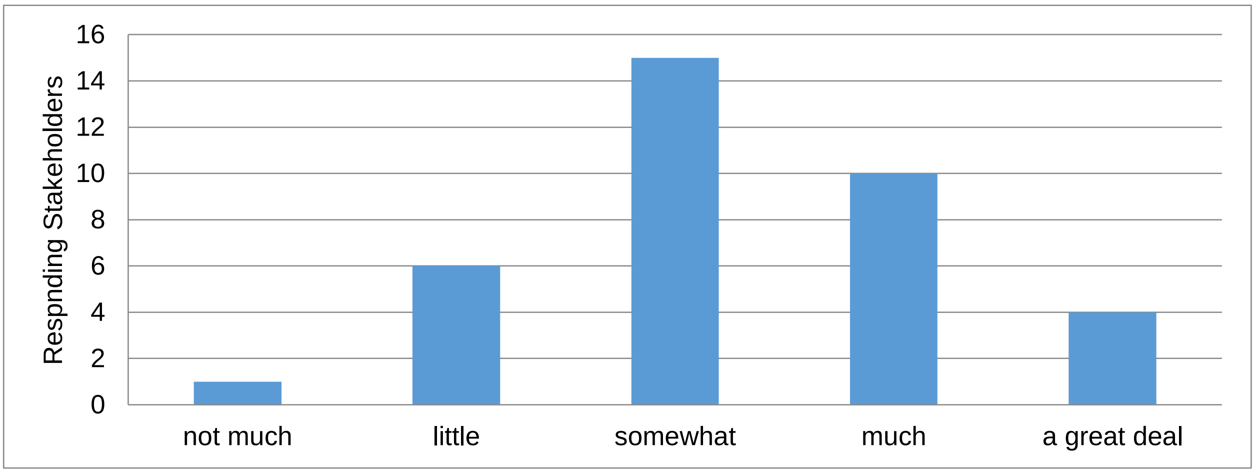


Figure 5.4 District heating stakeholders face major challenges with regard to the load profile of district heating networks.

There is a consent within the stakeholders that the use of renewable energies in district heating networks is of major importance. 60% would agree that the integration of energy flexible buildings is important or very important (Figure 5.5). They are mostly willing to upgrade the control system of the heating network and the buildings in such a way that the energy flexibility of connected buildings would be usable.

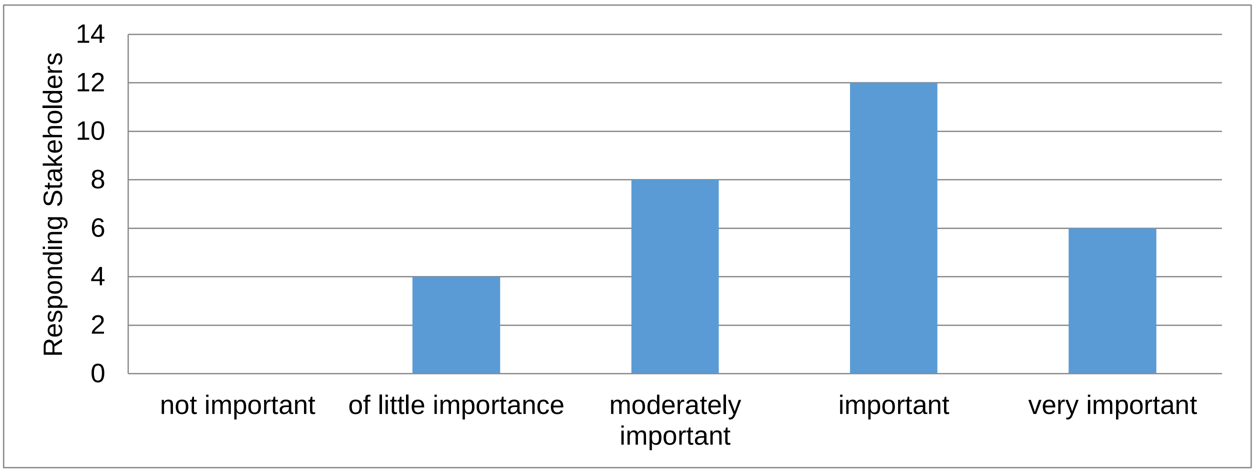


Figure 5.5 District heating stakeholders see the importance of energy flexible buildings.

The participants of this survey see less data privacy or market barriers, which could hinder the deployment of smart district heating grids, but more the high costs of technologies and insufficient development of these, as well as a lack of consumer awareness and appropriate regulations (Figure 5.6).

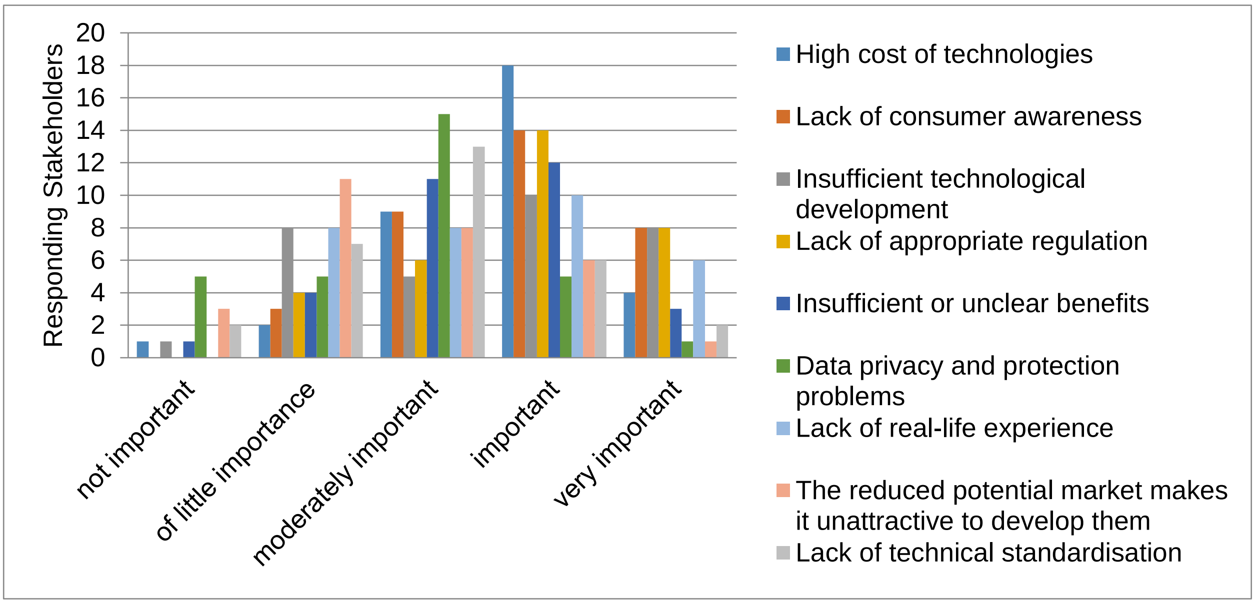


Figure 5.6 District heating stakeholders and the importance of barriers for smart heating grid implementation.

An interesting response came from the question on the amount of energy or load - as a share of their total heat generated – which they think could be shifted and/or saved: 60% estimate between zero and 20%, 30% from 20 to 40% and 10% above 40% would be possible. When asked about how to equalize possible additional costs for the operation of a smart heating grid to exploit load management and flexibility measures, the majority does not see higher prizes for the clients, but other cost benefits (Figure 5.7).

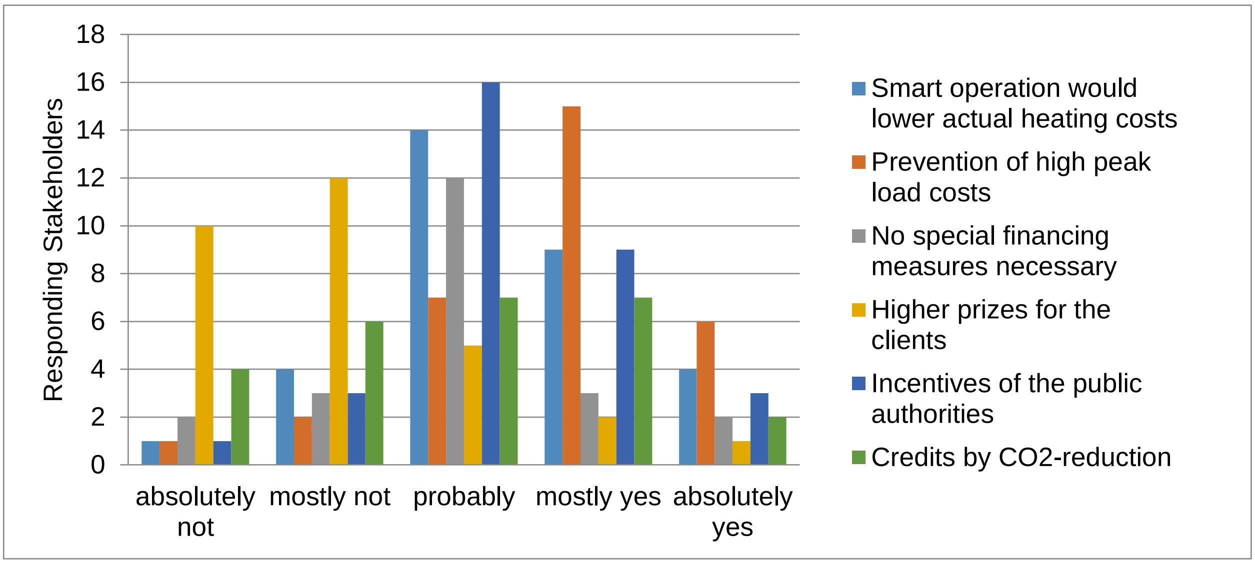


Figure 5.7 District heating stakeholders' thoughts about how to equalize possible costs.

Beside costs, stakeholders primarily see a lot of benefits to implement smart heating grids, e.g. to run the grid economically, to see how flexible the energy generation/distribution could be or how much money they could save with this. When it comes to the economic frame conditions, the stakeholders (at least two thirds) agree that innovative tariff models would be an incentive for clients (e.g. time-based or load-based tariffs), because they also think that insufficient economic compensation could be one of the most important barriers that will hinder clients from responding to price signals from certain tariff models.

Regarding the organizational influence of flexibility integration in district heating operation, the stakeholders assume that it is high – around two-thirds see a direct influence on their planning or operation in the future (Figure 5.8). And about the political frame conditions, also two-thirds answer that policy measures or directives for the dissemination of intelligent heating grids would be important or very important.

For the empirical social data, 94% of respondents were male, in total only 2 questionnaires were completed by females, and two-thirds of grid operators/suppliers have responded to this survey, of these more than 60% of them with a university degree and there was a normally distributed age range.

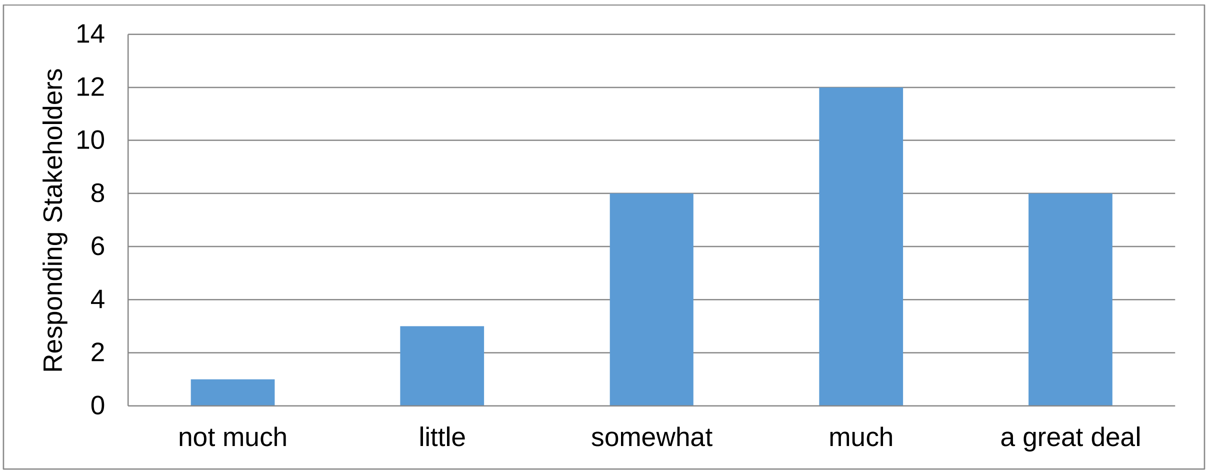


Figure 5.8 Future relevance and influence of concepts and technologies for intelligent heating grids.

5.5 Conclusions

Case 1 – 'DR opportunities and challenges for district heating suppliers in Denmark' presented the perspectives of a Danish district heating supplier on the concept of utilizing energy flexible buildings to gain benefits in the operation of a large district heating network. The case study was partially based on interviews in collaboration with a large district heating company (AffaldVarme Aarhus (AVA)) and partially based on a review of relevant literature.

In general, AVA considers energy flexible buildings as a tool that could provide benefits in the operation of district heating networks. From AVA's perspective, there is a large potential if flexible consumers could be used to reduce the overall heat generation capacity in the network. Analysis of the load duration curves, the temporal distribution of critical hours and the associated weather conditions indicated that the characteristics of the demand (in years 2015-2017) were well aligned with the duration at which buildings are capable of shifting space-heating consumption. Another potential solution associated with flexible consumers, is the ability to address congestion issues in parts of the network that undergo changes in demand. Furthermore, when pipes have reached the end of their service life, flexible demand may allow for a reduction in pipe dimensions, thereby generating savings throughout the year due to the reduced heat losses. Finally, flexible demand can be used to lower the uncertainties related to demand that affects both the sizing of new network components and the daily production planning, the latter especially in relation to the electricity markets.

The main barrier for utilizing flexible demand is the lack of infrastructure and the expense associated with installing the equipment at the consumers that is necessary for participating in demand response. Similarly, the district heating company does not currently have a method for determining the economic incentive that could be offered to flexible consumers. Related to this is the consideration of supply-fairness and the fact that incentives can only be offered to consumers in areas where flexible demand can generate savings for the supplier. Another barrier is the higher complexity of orchestrating demand response initiatives compared to centralized storage solutions such as heat storage tanks. The district heating company, however, acknowledge that flexible demand can solve issues that centralized storage cannot – for example, congestions in the distribution network. Finally, the district heating company argues that voluntary demand response schemes would be difficult for them to incorporate in their investment planning, as more certainty about the demand response participation rate is needed.

Case 2 – 'Stakeholder's perception and motivation on smart district heating grids using energy flexible buildings' describes the perception and motivation of district heating stakeholders for energy flexible operation of their energy networks, coupled with energy flexible building's control and management seen as clients. In Austria, there are a large number of district heating networks spread all over the country, but it is hard to reach them because they have a decentralized organizational structure. So only 37 respondents have been collected with relatively high effort – that was the challenging side of the survey. The interesting, and worthy of follow-up, results are:

- The relevance of the topic is higher than expected
- There seems to be a market for intelligent district heating concepts
- Renewable energy use in district heating grids is of high importance
- Cost, incentive and regulation related drivers and barriers are more important than data privacy or security issues

6. Aggregators for Energy Flexible Buildings

6.1 Introduction

Aggregators are a new player in the electricity market and an important stakeholder in energy flexible buildings. Most consumers do not yet have the means to trade directly into the electricity markets due to capacity and the complexity of participation. Aggregators can facilitate consumers by pooling electricity loads and sell their flexibility as a single unit in the electricity markets (Smart Energy Demand Coalition (SEDC), 2017). The role of aggregators can be undertaken by different stakeholders who can both existing and new market players, depending on the market conditions.

A case study discussing three aggregator models in two different smart energy systems is presented in the chapter. The case study aims to clarify the aggregators' roles and the new relationships caused by the aggregators' appearance in the markets. This case study also investigates the barriers for the aggregators to participate in the market, based on several interviews.

Table 6.1 Summary of data collection and results.

Purpose:	**Methodology**	**Targeted aspect**	**Result highlight**
Aggregators' activities and opinions	Case study	Aggregators Aggregator models Business opportunities	• Market stakeholders as TSOs and BR's believe that aggregators will play a major role in the utilization of building flexibility and DR • The role of aggregators can be undertaken by suppliers, BRP's and third party. • The aggregation potential can be in industry, buildings, and smaller units with a battery or storage facility as electric vehicles and heat pumps. • The main influential factors for aggregators to enter the building flexibility are 1) a clear definition and standardization of the aggregators' role in the market structure, 2) the technological development of DR equipment, 3) energy price reflects the market price and distribution conditions.

6.2 Background

Electricity stability and flexibility is essential to maintain high security of supply in the electricity system. The European Union (EU) has established significant goals to prevent the worst consequences of climate change. Several subsidiary goals contribute to the long-term goal of an 80-90% reduction in emission by 2050 when compared to 1990 levels (Delbeke and Vis, 2016). Furthermore, there is a global FN Paris Agreement to reduce greenhouse gas emissions and limit the global temperature increase (Briggs, 2017). Meeting the climate targets will be done, in the most part, by replacing fossil fuels with renewable energy and increased energy efficiency. When increasing the share of renewable energy sources, such as wind and solar energy, in the energy system, the energy production will become intermittent. In a balanced grid, the demand and supply must match each other, which is hard to control with a high amount of intermittent electricity production.

A way to deal with this problem is to make the electricity demand flexible by introducing demand-side management. Demand-side management includes everything that is done on the demand side of an energy system. This ranges from substituting an incandescent light bulb with a LED (light-emitting diode), up to implementing a complex dynamic load management system (Palensky and Dietrich, 2011). However, the focus will be on the market-driven aspects within the area of demand-side management. These aspects include the time of use of electricity and demand response. This is not well implemented in the scheme of the EU member states. However, demand-side management is an essential part of the future smart energy system to integrate more volatile renewable energy resources and meet the climate goals.

Aggregators are a central player in facilitating demand response and enhanced demand-side participation (Arentsen et al., 2017). The aggregator pools load of various types. Examples of this in the residential scheme are dishwashers, dryers, freezers, small heat pumps, and electric vehicles. In the commercial scheme, loads include those from heating, ventilation, and air-conditioning. In the industrial scheme, it is cold stores, pumps, smelters, roller presses, electric boilers and heat pumps for district heating (Ma et al., 2017a). In general, loads applicable for demand response are those that can be shifted to other times or functions, as stored energy. However, an aggregator needs specific experience and knowledge to identify the flexibility potential of each load process. The understanding the limitations and opportunities is essential to determine when to offer aggregation services to customers and to match the requirements in the electricity markets. Furthermore, an aggregator must have the technical capability to physically integrate customers' load into its portfolio. This requires advanced measurement, communication and control equipment, and software, which are capable of handling various loads with different properties.

However, although the potential for aggregators in the sector of energy flexible buildings is well discussed (Smart Energy Demand Coalition (SEDC), 2017), few studies have investigated it from the perspective of the business ecosystem and stakeholders' interaction and the energy flexibility in buildings is yet to be defined. Particularly, the cross-national aspect is missing in the literature, although knowledge exchange about the energy market structure and value creation could strongly influence the business opportunities for aggregators in the sector of energy flexible buildings.

6.3 Case 1- Aggregators in the future Danish and Austrian electricity market

6.3.1 Introduction

This section introduces the aggregators' roles and opinions regarding the energy flexible buildings based on the data from(Schultz and Friis, 2018). The thesis aims to investigate the motivation and barriers for demand response in Denmark and Austria. A comparison of the two electricity markets is conducted to identify and analyze the current and future business opportunities for demand response. The section introduces three aggregator models in Denmark and Austria, which clarify who undertakes the role of the aggregator and which new interrelationships occur. The models adopt the principles of the 'The Harmonised Electricity Market Role Model' by ENTSO-E (2015). The influencing factors affecting the business opportunities for aggregators in the energy market are investigated and discussed in the following to get an in-depth understand of the motivation and barriers aggregators are facing.

6.3.2 Methodology

Two countries: Denmark and Austria are selected in this case study. The comparative case study aims to investigate the needs and opportunities for aggregators in the electricity markets and fill the literature gap in across-national energy flexibility. The collected data in the two cases give a valuable understanding of the electricity market and different perspectives on the development of the electricity system, which is important for designing a model that shows the business opportunities towards a sustainable electricity sector.

The qualitative approach has been chosen in this case study to expand the knowledge on energy flexible buildings. Four face-to-face and semi-structured open-ended interviews are collected. The interviewees are selected according to their knowledge and market position. The selected interviewees have expert knowledge within the energy sector in Denmark and Austria. The Danish TSO - Energinet.dk and BRP- Danske Commodities contribute extensive knowledge about the Danish electricity sector and market opportunities for energy flexibility, while the Austrian TSO - Austrian Power Grid AG and BRP - Energie AG provide their knowledge about the Austrian electricity sector.

All interviews have been conducted at the interviewee's company and had a duration of around one hour. The interviews have been transcribed in English and decoded as preparation for the comparative analysis of the Danish and Austrian factors. Together with the literature review, this comparison will form the theorizing basis of the framework for demand response in the electricity market business ecosystem

Table 6.2 Interview content.

	Contents
Future energy system	Which solutions must be implemented in the future electricity system to maintain the security of supply and competitiveness in the market due to more renewable energy sources?
	What is the potential for demand response in the future electricity system?
Development in the electricity system related to demand-side management	What are the current barriers for demand response in the electricity market?
	Which specific initiatives are currently carried out to promote demand response?
	What future steps need to be taken to remove the barriers for demand response in the electricity market?
	Which electricity market is most appropriate for implementing demand response?
	How can demand response be bid for these markets?
Settlement of electricity	How is the settlement for consumers with different capacities?
	How must the settlement be modified to allow smaller consumers to participate in demand response?
The role of the aggregator	Do you see individual units performing demand response in the future, or will an aggregator undertake this service?
	Who could potentially undertake the role of being an aggregator? (third party/independent player or established market player?)
	How should the implementation of aggregation be financed?
	Will demand response cause any negative consequence? If any, which?
Flexible consumption units	Which consumption units can be used for aggregation?
	How can these consumers be motivated towards providing demand response?
	Can you estimate how much flexible consumption is available in your portfolio of consumers?

6.3.3 *Results and discussion*

The aggregator role is necessary to facilitate flexible consumption in buildings. From the interviews with experts in both Denmark and Austria three different Stakeholders in the smart energy ecosystem are listed as potential aggregators:

- Independent third-party aggregator
- Suppliers

- Balance Responsible Parties

Aggregators’ preferences and concerns for DR control options

It is possible for existing market players to undertake the role as an aggregator. They can collect all small consumer units as one unit, which can bite into the market. This a simple and easy way to perform aggregated DR and it will work well with the existing market structure. A third party with special knowledge of e.g. heat pumps or electrical vehicles, acting as an aggregator will be more complex to start up compared to an already existing market player undertaking the role of being an aggregator. A third party needs an agreement with both the suppliers and the BRP before entering the market. This is a lot more complicated since all heat pump owners do not have the same electricity supplier and BRP for example.

From the interview, three different models of how aggregated DR can be a reality and how the interaction with other stakeholders could be arranged is investigated.

- *Model 1: Existing Market Stakeholders as Aggregator*

This model outlines the current options for the aggregator role, where existing market stakeholders undertake this role. In this model, an existing electricity supplier or BRP (balance responsible party) act as an aggregator, or they have made an agreement with an aggregator, which makes them appear as a single player to the customer. This model is aimed toward players who are energy suppliers or BRPs in the market. These players are already in contact with customers. This makes the model less complex concurrently because only one BRP is related to each customer.

New products can enter the market to promote demand response. The flexible electricity settlement for small consumers will be one of these new products, but also variating tariffs from the DSO or even the TSO will strengthen the business case. The new service products also imply that the aggregator is authorized to manage and optimize the energy consumption with requirements set by the customers. The requirements could, for instance, include the delivery of heat and transport services.

The model is already used by a Danish BRP who have agreements with owners of electrical boilers. The model, however, does not allow for independent aggregators and there is still need for promoting awareness about the possibilities in the electricity markets. Many electricity suppliers and BRPs do not have an aggregation of flexible consumption within their business model, which might lead to a leak and specialization and full utilization of the DR unit. Because of the already exciting customer contact between the energy supplier and the individual customer, it would be easier for the energy supplier to act as an aggregator compared to the BRP. The BRP does not have the same customer contact and therefore is most interested in acting as an aggregator for large consumption units, e.g. electrical boilers.

- *Model 2: Flexibility Provided by Independent Aggregator*

In this model, the independent aggregator delivers flexibility but not electricity. The energy supply is provided by the consumer's existing supplier and its associated BRP. The consumption is thereby split into classic and flexible consumption. The aggregator controls the flexible consumption and has its own BRP, who enables the aggregator to deliver flexibility to all electricity markets. The imbalance costs are managed by the aggregator and its BRP in the activation periods. This means that two BRPs are associated with the customer - one for the classical consumption and one for the flexible.

This model is more complex since a clear division of responsibilities between market players must be defined and a method for validating the activation periods for flexibility must be developed. This is due to the challenges of accounting and imbalance settlement between the two BRPs. If this challenge can be solved, this model is interesting due to the low entry cost since only one metering point per customer is needed.

In this model, the aggregator is not obliged to pool loads from the same supplier, since the aggregator has its own BRP and no electricity is delivered - only flexibility. It is thereby easier for the aggregator to create the most optimal pool. Furthermore, this model enables the customer to have multiple aggregators, e.g. one aggregator for the heat pump and one for the electric vehicle.

- *Model 3: Flexibility and Electricity Provided by Independent Aggregator*

In this model, the independent aggregator delivers flexibility and electricity. Several metering points are installed to separate the flexible consumption from classical consumption. Electricity supply and flexibility control are integrated into single devices, such as heat pumps or electric vehicles, and the service is provided by an aggregator. Because of the technology development, it is expected that it will be possible to perform demand response with e.g. household appliances, where the control equipment is integrated into the appliance.

This model makes a clear division of responsibilities as well as the accounting and settlement between BRPs. This is because metered data from the separate metering point can be used as validation of the aggregator's activation of flexibility and for settlement of electricity as well as the imbalance settlement with the aggregator's BRP. Since the aggregator handles both electricity and flexibility, no unintended costs are imposed on other players. Because of the several metering points needed in this model, the entry costs per flexible unit is relatively high, which hinder the facilitation of independent aggregators. However, the complete separation of responsibility makes the model easy to understand for all players in the market.

The main differentiator between the three models of Denmark and Austria are the data and information exchange between market players. In Denmark, all market players receive the needed data from the DataHub, while in Austria they need the DSO and TSO to provide them with data and send data to both the TSO and the Imbalance Settlement Responsible. There are otherwise no considerable differences since the role definitions in the two business ecosystems are comparable and the aggregator role is identical.

Motivation, barriers, and concerns for DR program participation

There is a consensus among all interviewees that aggregated demand response will gain a foothold in the electricity markets and will play an important part in the future electricity system. However, there appear different viewpoints among the interviewees on where the future potential will occur, in large industry or in buildings and households. The Austrian BRP, Energie AG, states that the demand response potential in the large industry is already utilized since they are already hourly settled and seeks to optimize their profit. Thus, the potential is to be found among smaller consumers. Energie AG substantiates this by: "We see wholesale prices hourly or a quarter of an hour, but the customers do not see these prices, this means that there must be some flexibility within households or industry which are not used yet". However, the Danish and Austrian TSOs still see potential within large industries. Though, some interviewees state that the potential among the smallest consumers are limited and will not have a significant influence on the electricity system. They state that the consumption must have a considerable size and associated with energy storage.

The business opportunities and value creation for becoming an aggregator are influential by some external factors which can be divided into Climate and environment, Social Culture, Technology, Economy and finance, and Policy and regulation. Table 6.3 shows the top influential factors and the correspondent aspects.

Table 6.3 Top Influential factors and the correspondent aspects.

Aspects	Top influential factors
Market structure	Distribution of roles and responsibilities related to aggregation must be clearly defined and standardized. Development of market conditions that enable explicit demand response in the electricity markets.
Technology	Technology development of demand response equipment Electrification, different units to be controlled. Creates more need for DR. Sector coupling is necessary to improve the economic benefit of demand response.
Financial	The energy prices that reflects the market price and grid conditions by introducing different tariff models, removing or lowering taxes and a generally more variating market price will make it more profitable for the end user and thereby increase the business opportunities for an aggregator in the market.

The interviewees all agreed that an important factor for incentivizing aggregated demand response is the electricity price. Generally, the interviewees forecast that the electricity price will decrease due to the increased share of renewables in the system and a lower marginal price of electricity production. This also entails a more fluctuating electricity price caused by the volatile renewable electricity production, which encourages demand response. However, the Austrian TSO has the interesting remark that a power production entirely based on renewables, with a fixed marginal cost of zero, is contrary to the current neoclassical market design. Thus, they suggest redesigning or rethinking the market structure to overcome this issue and propose a fixed settlement, which corresponds to the payment method as seen in telecommunication as a possible solution. Variating settlement schemes can be seen as a motivation factor for aggregators and DR while a fixed price should be a concern.

The Austrian TSO mentions another interesting subject related to demand response, namely the use of ’blockchain’ in the electricity system. The most well-known conceptualized case of blockchain is cryptocurrencies such as Bitcoin. This might play a major role in the future electricity system and outmatch the need for aggregators. It facilitates automatic and direct trade of electricity between consumers and producers, which is ideal for demand response. However, introducing blockchain in the value chain of the electricity system will rearrange the business ecosystem completely; all intermediaries between producer and consumer will be excluded and their function will be carried out by software. Electricity trade will become frictionless and transaction costs will be lowered considerably while the business ecosystem will become simpler in case of buying and selling electricity.

6.4 Conclusions

The result of the case study reveals business opportunities for demand response. It has been ascertained that the two selected electricity markets have a lot in common with several aspects. Currently, it is only legally possible to participate in the demand response programs in Austria but not Denmark. Although demand response will play an important role in the future smart energy system, how and to what extent is yet uncertain. The case study shows that the aggregator role can be undertaken by different stakeholders in the three different aggregation market models. For instance, in some DR markets, the existing market players, as supplier and BRP, undertake the role as an aggregator, and the independent aggregators are allowed in some DR markets.

The result shows that there are some specific conditions that affect the business opportunities for energy flexible buildings: aggregators’ roles and responsibilities must be clearly defined and standardized; the market conditions that enable explicit demand response in the electricity markets are necessary; a technology development of demand response equipment, electrification and sector coupling is necessary to improve the economic benefit of demand response; the electricity prices should reflect the market price and grid conditions by introducing different tariff models, removing or lowering taxes. Furthermore, the results imply that a single but potentially useful demand response service product cannot succeed unless the market is well-functioning across all parts of the value chain. Consequently, companies do not participate in demand response until the market challenges are resolved.

7. Technology Providers for Energy Flexible Buildings

7.1 Introduction

Technology providers are essential to the realization of the energy flexibility potential of buildings through e.g. model predictive control (MPC). The technology needed for MPC can be divided into 1) hardware, i.e. sensors, meters, and actuators including their communication infrastructure, and 2) MPC software. Existing commercial hardware products from technology providers rooted in the traditional building automation industry are, to a wide extent, also the hardware needed for MPC. Standard building automation solutions for modern commercial and industrial buildings often hold the hardware infrastructure needed for MPC, e.g. indoor climate sensors, energy meters, and online actuators on HVAC systems. The emerging market of smart home automation also brings hardware into homes that could be used for MPC. Common for state-of-the-art building automation products (commercial building or home products) is that their control system consists of P, PI or PID controllers for which certain fixed rules/schedules can be applied; MPC algorithms in commercial systems are currently non-existent, probably because there currently is no business case or requirements from society.

However, an increasing number of research projects propose and test MPC algorithms using existing, commercial building automation hardware. The following section describes a prototype that utilizes existing commercial hardware for MPC of hydronic space heating systems. The principle is to utilize the thermal mass of structural building components to achieve energy flexibility. This section contains a description of the technical infrastructure (hardware and MPC), an experimental setup to test the concept, and the preliminary results from this test. Finally, reflections on the current technological challenges related to the realization of MPC are provided.

Table 7.1 Summary of data collection and results.

Purpose	Types of Building	Methodology	Targeted aspect	Result highlight
Technology providers: objectives and challenges	Residential or commercial buildings	Experimental study	A prototype implementation of MPC schemes that enable flexible consumption	• The results indicate that technology providers already have the hardware needed for MPC. • More efforts should be put into the development of robust and reliable MPC algorithms. • Cost-efficient building automation hardware for non-commercial buildings (homes) should be developed.

7.2 Background

Model Predictive Control (MPC) is a promising control framework for enabling buildings to participate in demand response (DR) programs, tailored to provide energy flexibility for the energy system as a whole. A specific application is MPC of heating systems that seeks to utilize the thermal mass present in buildings for DR purposes. The theoretical potential for this has been investigated in numerous simulation-based studies, e.g. (Hedegaard et al., 2017, Pedersen et al., 2017, Bianchini et al., 2016, Dahl Knudsen and Petersen, 2016, Reynders, 2015). These studies have demonstrated that MPC has a theoretical potential to reduce the energy bill of consumers, reduce CO_2 emissions, and shift consumption away from peak periods in the energy system. The current barriers for large-scale applications are 1) an overall need for the development and documentation of reliable and robust MPC technologies and schemes, and 2) to verify the identified theoretical potentials through reliable experimental studies. The following section describes a proof-of-concept experiment featuring a prototype MPC setup.

7.3 Case 1 – Test of MPC technology prototype

7.3.1 Introduction

An MPC prototype was developed using radiator actuators and indoor air temperature sensors connected to a commercial building automation substation from Trend Technologies. The substation could be accessed remotely over the local area network. The MPC algorithm was established in MATLAB and relied on a grey-box model of the thermal zones in which the MPC was used to operate space heating.

The daylight laboratory facility at Aarhus University (Denmark) was used as a test facility for the MPC prototype. The laboratory is located on the roof of the building Navitas and consists of two similar experiment rooms with the same geometry and technical properties, a control room, a staircase, a hallway and a technical room as illustrated in the floor plan in Figure 7.1. This side-by-side facility enables cross-over experiments where a reference type of control is employed in one room (setpoint tracking) while the other room is controlled by the MPC.

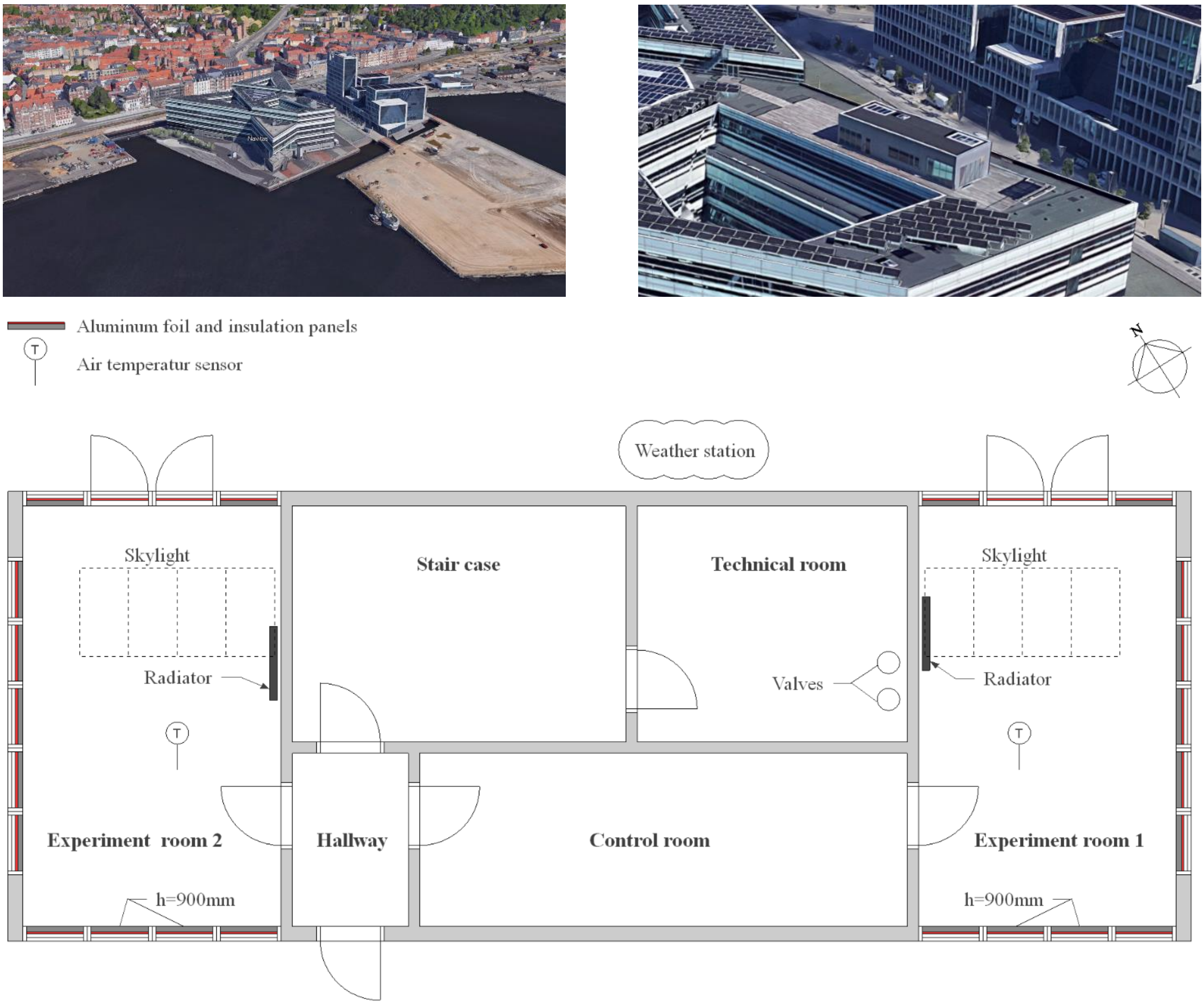
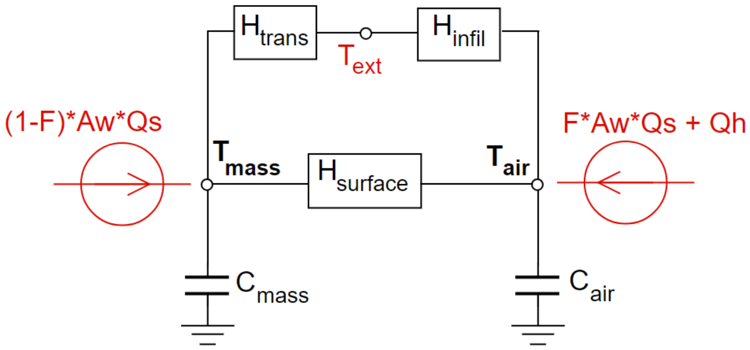


Figure 7.1 Placement floor plan and of the daylight laboratory at Navitas, Aarhus University.

7.3.2 Methodology

The control model for the MPC was formulated as a linear two-state grey-box model representing the lumped thermal capacity of the room air and the construction elements, see figure 7.2.

A four-week excitation experiment was carried out to make data for estimation of the grey-box control model needed in the MPC. Measurements of the air temperature in the two experiment rooms, respectively, together with ambient weather conditions measured on the roof of the laboratory during the excitation period are displayed in figure 7.3. The experiment period was divided into a training and validation period, and data in the training period was used to estimate control-model parameters by minimizing the multiple-step ahead prediction error, while the remaining data was used for control-model validation. The normalized root mean square error (NRMSE) of the control models was 65% and 71% for experiment room 1 and 2, respectively, during the validation period. The trajectory of measurements and control model output during the validation period are depicted in Figure 7.4.



Parameters:

T:	Temperature [K]
C:	Thermal capacity [J/K]
H:	Heat loss coefficient [W/K]
Aw:	Solar aperture [m2]
F:	Solar distribution ratio [-]

Inputs:

Text:	External air temperature [K]
Qs:	Global solar radiation [W/m2]
Qh:	Heating power [W]

Indexes:

air:	Zone air
mass:	Thermal mass
surface:	Internal surfaces
trans:	Heat loss due to transmission
infil:	Heat loss due to infiltration

Figure 7.2 Model structure.

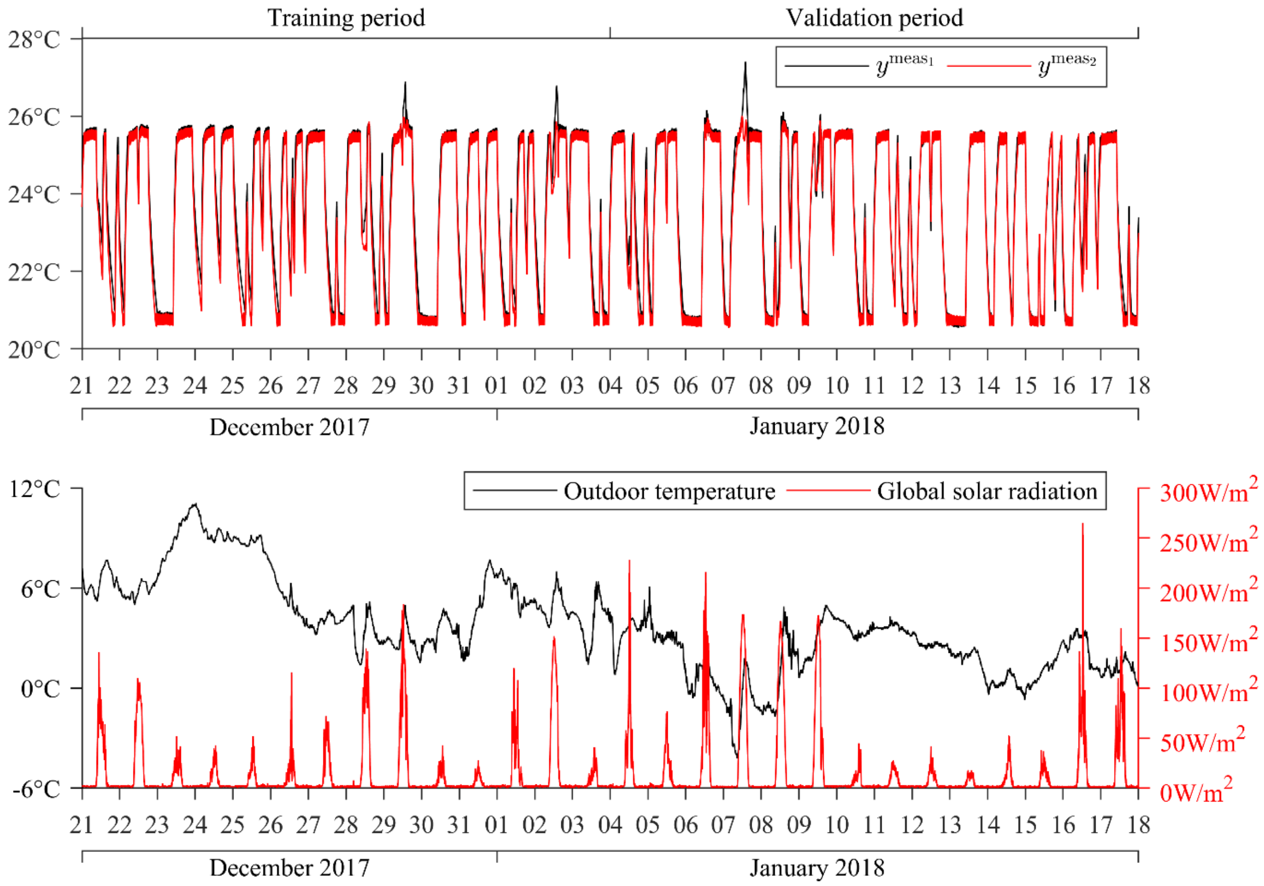


Figure 7.3 Four-week excitation experiment data.

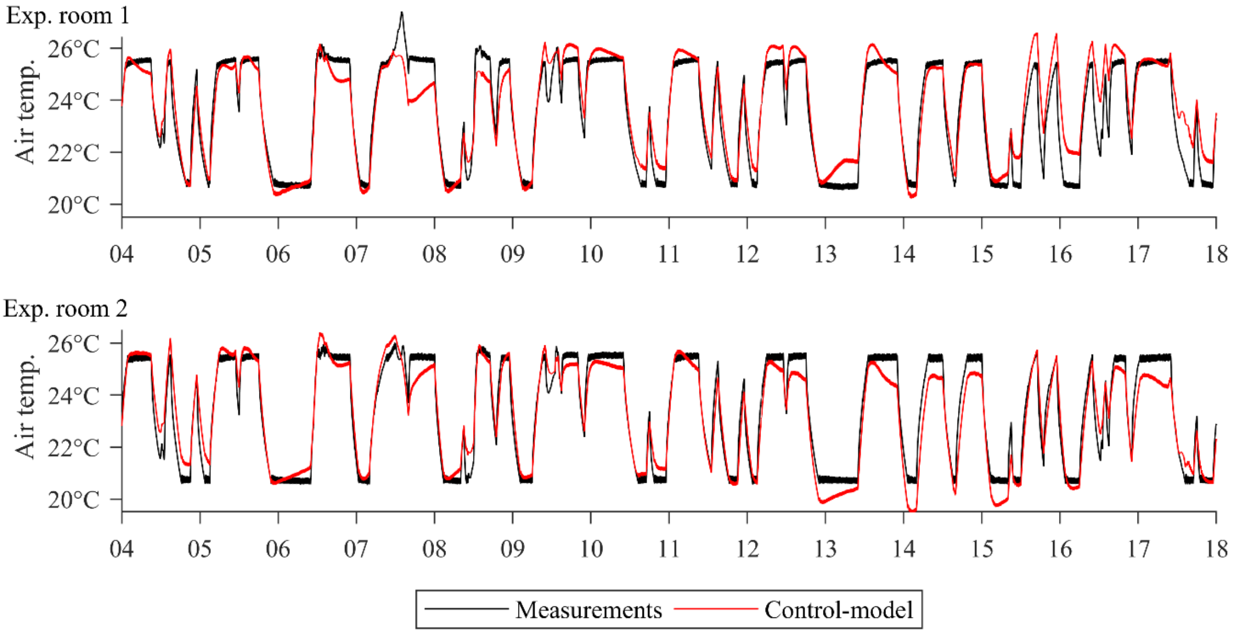


Figure 7.4 Measurements and control model output during the validation period.

The whole (linear) MPC scheme is illustrated in figure 7.5. The scheme makes use of the identified control models to determine an optimal heating setpoint y_τ^{set} at each time step τ, constrained by the time-invariant bounds t^{min} and t^{max} of 20°C and 26°C, respectively. The setpoint is sent to the the Trend substation where a conventional PI-loop adjusts the valve opening θ_τ, and a driver consequently adjusts the water flow q_τ to the hydronic radiator to achieve y_τ^{set}. The heat delivered to the room and the air temperature denoted Φ_τ and y_τ, respectively, are measured and returned to the MPC scheme, thus introducing feedback. Disturbances $\boldsymbol{d}_\tau$ acting on the room, i.e. outdoor temperature and global solar radiation, are measured and returned to the Economic-MPC (E-MPC) scheme. Furthermore, weather forecast provided by the Danish Meteological Institute, and the cost signal $\boldsymbol{f}$ for the prediction horizon N are communicated to the E-MPC scheme.

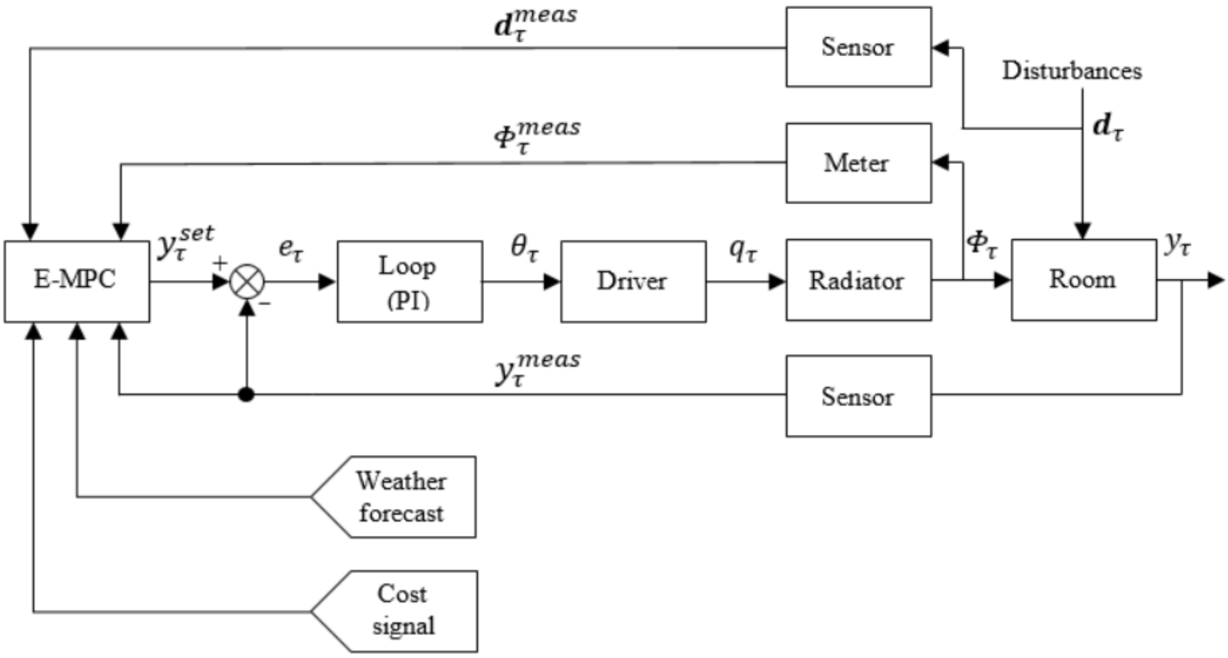


Figure 7.5 Block diagram of implemented prototype MPC setup.

The prototype E-MPC scheme was applied in experiment room 2 (figure 6.1) while experiment room 1 tracked $t^{\min}$.

7.3.3 Results and discussion

Measurements of the air temperatures, heating power, and ambient disturbances during a six-day period of the experiment are depicted in figure 6.6. Data shows that the experiment rooms are very sensitive towards solar heat gains, which is indicated on two occasions where the air temperature significantly exceeded $t^{\max}$ while the heating power was 0 W. The small oscillations of the air temperature was due to delays in the hydronic heating system, tuning of PI gains and building/control-model mismatch.

The objective of the MPC scheme was to minimize heating consumption in high price periods (marked with grey), by increasing the air temperature during low price periods to charge the thermal mass. The achieved results are listed in Table 7.2 where the heating consumption during the six-day period is summed for the two experiment rooms. While the MPC used more energy in total, $\boldsymbol{\Phi}^*$, the variables $\boldsymbol{\Phi}^{low}$ and $\boldsymbol{\Phi}^{high}$**,** that specifies the relative amount of Φ that was consumed during high and low price periods, indicate that a significant amount of the consumption was shifted to the periods with low prices.

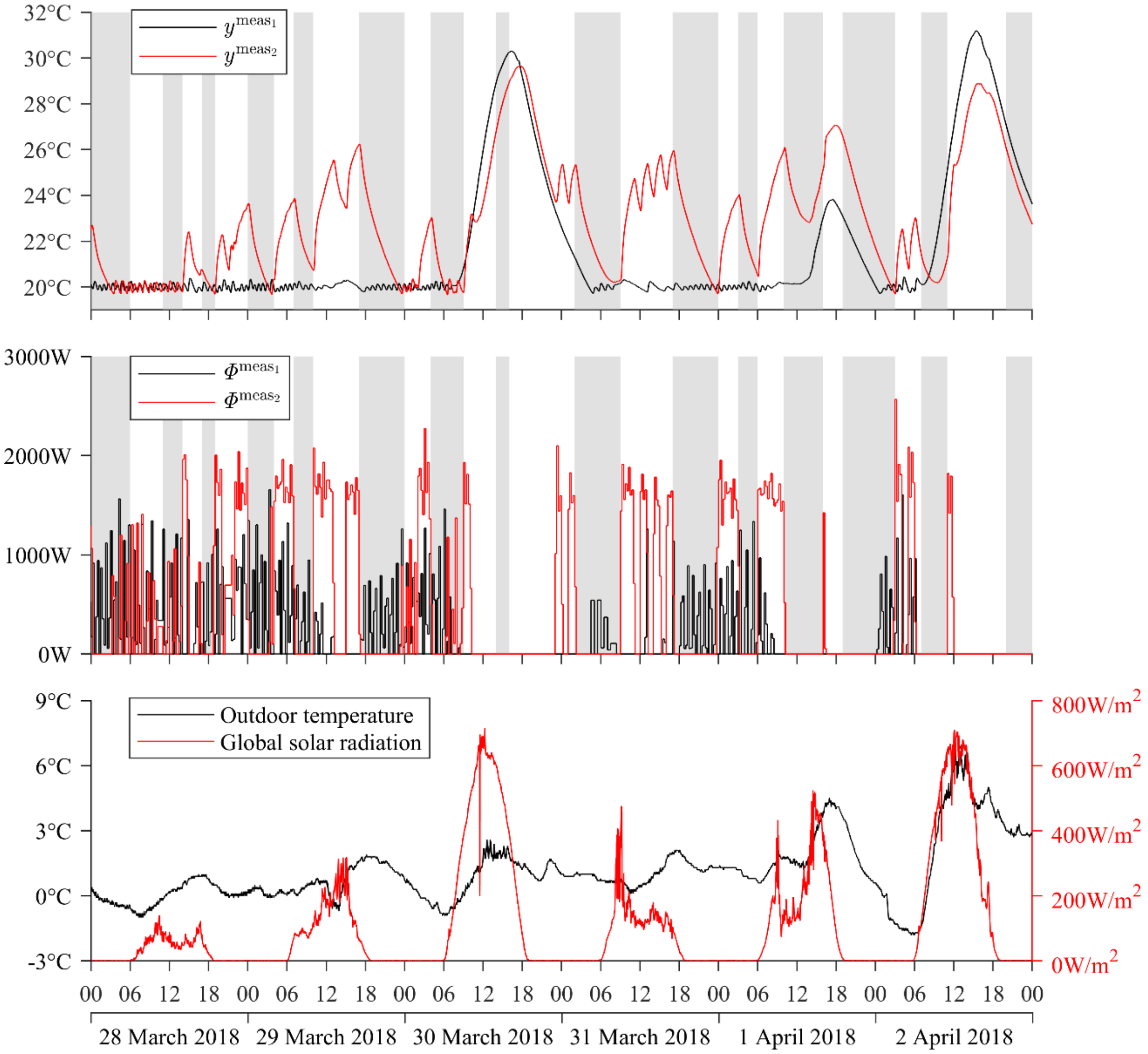


Figure 7.6 Measurements obtained during a six-day period.

Table 7.2 Summarized experiment results.

	Φ^*	$\bar{\Phi}^{\text{high}}$	$\bar{\Phi}^{\text{low}}$
Experiment room 1 (reference control)	1.4 kWh/m2	54.5%	45.5%
Experiment room 2 (two-level MPC scheme)	1.9 kWh/m2	26.4%	73.6%

The test of the MPC prototype indicates that existing hardware from a well-established building automation technology provider can be used for MPC. The hardware setup used in the experiment is a standard product for a building with many zones, e.g. an office building; it would be infeasible to invest in this hardware for MPC of e.g. a detached single-family house. Therefore, a remaining barrier for utilizing MPC to utilize energy flexibility in residential buildings is the need for cost-effective and wireless solutions designed for the residential sector.

The realization of MPC currently relies on real-time data flow from many different sources: temperature sensors, energy meters, weather forecast, on-site weather measurements, and a DR signal. Consequently, there is a need for developing robust and reliable MPC solutions that minimize the risk of any undesired effects from loss of data flow. A step toward more robust solutions may be to omit the hardware needed for on-site weather measurements and just use the weather forecasts instead as suggested in (Hedegaard et al., 2018).

7.4 Conclusions

The results from the test of a prototype of the two-level economic model predictive control setup, including the necessary hardware and technological infrastructure, indicates that technology providers already have the hardware needed for MPC. However, more cost-efficient building automation hardware for non-commercial buildings (homes) are needed. Overall, efforts should be put into the development of robust and reliable MPC algorithms.

8. Energy consulting and analytics in Energy Flexible Buildings

8.1 Introduction

It is important to investigate the motivation and barriers for energy flexibility in buildings from an energy consultancy and analytics point of view. Practitioners in this field have a robust interdisciplinary understanding of the energy market and can connect the building owners'/ building managers' needs with the market conditions. This section introduces two case studies with operators in the energy consultancy and analytics market that aim to investigate their participation and opinions on energy flexible buildings.

Table 8.1 Summary of data collection and results.

Purpose	Methodology	Targeted aspect	Result highlight
Energy consultancy' opinions	Interviews	Regulation and policies Tariffs and taxes Market condition and microgrids Stakeholders' collaboration	• The complexity of the energy system regulation makes the energy system very difficult to be more flexible. • The requirement for providing energy flexibility to the grid is high and complicated. • One large barrier to energy flexibility is the tariffs and taxes associated with power production. • Smart meters with two-way communication and hourly electricity pricing must be implemented to create an incitement for energy flexible buildings. • Unclear schemes for buildings to provide energy flexibility: either everyday flexibility or emergency. • Communication between energy suppliers and consumers is important.
Roles of energy analytics'	Interviews	Regulation and policies Tariffs and taxes Market conditions and aggregators Stakeholders' collaboration	• The implementation of flex settlement need to be a reality for all, also consumers with a supply unit like photovoltaics (PV), to promote energy flexibility in buildings. • The access to data from the consumers is complicated. • Greater fluctuation of the electricity spot price will create an incentive to move consumption and save money. • The electricity price should reflect the grid and market condition instead of a price with fixed tariffs and taxes. • Collaboration between market stakeholders and consumers are important to success with the interdisciplinary implementation of energy flexibility in buildings.

8.2 Background

Energy consulting and analytics play an important role in the development of energy flexible buildings; these services can support the success of demand response. The success of demand response is related to various factors, for example, regulation, consumers' motivation and electricity suppliers' support (energinet.dk, 2011). Energy consulting and analytics can support energy decision analysis, customize solutions based on buildings' needs and establish communication among related stakeholders.

For instance, buildings can provide flexibility to the energy system in various ways, e.g. load shifting and HVAC (heating, ventilation, and air conditioning) control, and participate in two types of DR (demand response) programs: explicit and implicit demand response. The two types of DR programs are activated at different times and serve different purposes in the markets. Consumers typically receive a lower bill by participating in a dynamic pricing program (implicit DR), and receive a direct payment for participating in an explicit demand response program (Bertoldi et al., 2016). However, to participate in the DR market by providing energy flexibility, buildings are required to comply with the requirements of DR programs. For instance, to participate in the electricity regulating market in Denmark, the requirement is a minimum electricity supply of 10 MW, which is much higher than an individual building can provide. Meanwhile, the investment cost to install a system that matches the requirements is considered to be too high.

There are more significant incentives for buildings equipped with building automation to participate in the demand response programs, that buildings can be automated on a large scale with small enough effort. In theory, for building automation, building managers could remove the controllability from the occupants, and simply enforce changes – such as lighting control or temperature control. However, this would lead to dissatisfaction, so it is unlikely for building managers to consider changing occupants' energy behaviour. Especially, without sufficient incentives, it does not make sense for consumers to change comfort and behaviour.

Normally, various parties involved in the building control and energy programs have different agendas. This can make the system more versatile, but it can also make it inefficient since it must comply with different agendas. For instance, electricity suppliers communicate with their consumers by smart metering, and electricity suppliers believe that providing hourly electricity price and consumption information can create opportunities for consumers to provide energy flexibility to the grid.

Collaboration between different actors in the market is important for the joint goals of energy flexibility to become a reality. For instance, a district heating company and an energy consulting company can collaborate to analyse energy information and provide analytical reports to their partners and customers. By this way, all their members have the possibility to explore new opportunities created by incentives.

8.3 Case 1 – Energy consultancy in the Danish energy flexible buildings

8.3.1 Introduction

This case is from the same project as ‘case 1.1 - building managers in energy flexible campus buildings’ (Ma and Jørgensen, 2018). The project aimed to investigate the motivation and barriers for energy flexibility in buildings by conducting interviews with building automation suppliers, electricity supplier, district heating supplier, distribution system operator, energy service companies, experts in energy and buildings, building managers, and occupants. This section introduces the energy consultancy’s opinions regarding energy flexible buildings (Ma and Jørgensen, 2018).

8.3.2 Methodology

This project adopts the qualitative methodology of interviewing to examine and report the experience acquired by various stakeholders. One interview with the energy consultancy in Denmark - Grøn Energi, was conducted as a semi-structured face-to-face interview with a chief analyst. Grøn Energi works with analytics and innovative projects that can illuminate and document the key role that district heating has in the future of the Danish energy system. The interview questions are shown in Table 8.2.

Table 8.2 Interview content.

Category	Interview question
Energy Policies regarding energy flexibility and efficiency in buildings	Which opportunities do you see campus buildings have in the future energy system? What barriers stop current and future buildings to become a part of a smart energy system? Concerning electricity and heating How can these barriers be removed? And how can we create incentives instead?
Communicating Information	How does your company communicate information regarding reducing the energy demand in large buildings? Heating demand or electricity demand? What kind of recommendations (or the like) for reducing energy demand in large buildings, do you communicate to your customers/network? Heating demand or electricity demand? Do you think that the decision makers for improving energy efficiency in large buildings consider reducing their energy demand? What do you think will be the main incentive for these decision-makers to improve energy efficiency and flexibility? Their PR, their energy costs or something else?
Authority Responsibilities	What should be done by local authorities regarding managing the local building projects to promote energy renovation? How should the municipality use zoning and other tools to secure more energy efficient buildings being built?
The Future Heating System	How do you see the future energy systems for large buildings?

8.3.3 Results and discussion

Regulation and policies

The complexity of the energy system regulations makes it difficult for the energy system to become more flexible. The interviewee believes that Danish legislation needs to be changed to further promote the implementation of flexible energy systems.

The requirement for providing energy flexibility to the grid is high and complicated. Compared to the rewards, the investment cost to install a system that matches the requirements is considered to be too high. Meanwhile, it would motivate smaller consumers to provide energy flexibility if the regulations and legislation can be easier to fulfil. Nowadays, to participate in the electricity regulating market in Denmark, the requirement is a minimum electricity supply of 10 MW, which is much higher than an individual building can provide.

Politics have an influence on the Danish energy system and where solutions and incentives come from. Whenever a large change is needed on the demand or production side of the system, politics are the initiator or the executioner for creating incentives for using new technologies or excluding older technologies.

For instance, large data centres are going to be built in Denmark, Facebook in Odense, Apple in Viborg, Google in Fredericia, and have already created incentives to reduce or remove the levies tied to the use of heat pumps, entirely. With a deal made with the Facebook data centre, Fjernvarme Fyn in Odense, Denmark will be able to receive the excess heat and avoid the investment cost for replacing an old district heating plant. It shows that special rules can apply if a larger change would happen to the system with socio-economically benefit.

Therefore, politicians are the decision makers for creating incentives for buildings to become either energy self-sufficient, an integrated part of the grid or both. According to the interview with the energy consultancy, levies are the deciding factor for buildings to provide energy flexibility with socio-economic impact.

Tariffs and taxes

One large barrier to energy flexibility is the tariffs and taxes associated with power production. For instance, the company-Modkraft3 conducted an experiment to offer consumers free electricity at nights. However, the problem is that the consumers still need to pay the same tariffs as purchasing electricity, which in fact are the main part of the original cost. Therefore, the cost is not significantly reduced. As tariffs cannot be reduced, the incentive for behaviour change is minimal. In Denmark, PSO (Public Service Obligations) is going to be removed during the period of 2017 – 2022, and the removal of PSO can increase the renewable energy resources and also be expected to encourage more electricity consumption due to the cheaper electricity price without the PSO.

Market condition and microgrids

For the preparation of a future smart and flexible energy system, smart meters with two-way communication and hourly electricity pricing must be implemented to create an incitement for building owners to regulate their energy consumption. By doing so, the peaks in the system can be shifted by using demand response management (DRM). The energy system can be optimized using flexible devices and therefore become more stable.

The Danish government has already begun the process of smart meter installation. According to section 2 of the Danish Act on Smart Meters and Metering of Electricity at the End User (Energistyrensen, 2013), all end-users must have smart meters by December 31, 2020. This is the first step toward hourly pricing, but a final step is still needed. New legislation may push the system in a certain direction, but often companies and their policies determine the technologies.

A greater incentive for energy flexibility would be the establishment and operation of microgrids, especially in countries without strong and stable grids. Denmark is a small country with a strong grid, and the need for energy flexibility is, therefore, less urgent. Denmark is currently on two separate tracks when it comes to supporting the increased integration of renewable energy. On one hand, new interconnections are made to trade electricity internationally, and on the other hand, the potential for increasing the amount of flexibility is being investigated.

There are two sides to introduce more self-sufficient buildings. For a system response, the increasing number of islanded systems connected to the main grid would result in more peak plants, which would not be a reliable solution. Another downside to the island mode of larger buildings is that the district heating network loses a customer, which increases the heat costs for the rest of the network's customers.

Another important question is what the energy flexibility in buildings is supposed to accomplish: is it everyday flexibility or in case of emergency? It could become much cheaper to utilize flexible consumption instead of having large production facilities on standby in case of emergency. In the near future, data centres are being built in Denmark, which will not use flexible consumption and therefore become a baseload. This is likely to create an incentive for energy flexibility in other buildings.

Stakeholders’ collaboration

Communication between energy suppliers and consumers is important. For instance, electricity suppliers communicate with their consumers by smart metering, and electricity suppliers believe that providing hourly electricity price and consumption information can create opportunities for consumers to provide energy flexibility to the grid.

Energy suppliers try to communicate with buildings regarding incentives for energy efficiency. For instance, a district heating company and an energy consulting company collaborate to analyze energy information and provide analytical reports to their partners and customers. By these means, all their members have the possibility to explore new opportunities created by incentives.

Collaboration between different actors in the market is important for the joint goals of energy flexibility to become a reality.

8.4 Case 2 – The role of energy analytics in the energy flexible buildings

8.4.1 Introduction

This case is from the same source as used in Chapter 6 (Schultz and Friis, 2018). The aim was to investigate the motivation and barriers for demand response in Denmark and Austria by conducting interviews with electricity suppliers, district heating supplier, distribution system operator, energy service companies, and experts in energy and system regulators.

This section introduces the energy analysts' opinions regarding the energy flexible buildings (Schultz and Friis, 2018).

8.4.2 Methodology

This project conducts three interviews, including one interview with the Danish electricity supplier Energi Fyn, one with the Austrian TSO Austrian Power Grid AG, and one with the Austrian electricity supplier Energie AG. The results of this case are mainly based on a semi-structured face-to-face interview with analysts within the scope of energy flexibility. All the companies have a great knowledge about the energy system and especially energy flexibility. The interview questions are shown in Table 8.3.

Table 8.3 Interview content.

Category	Interview question
Future energy system	Which solutions must be implemented in the future electricity system, when more volatile renewable energy sources are installed, to maintain the security of supply and competitiveness in the market? How does the transition of the electricity system affect your company? How great is the potential for demand-side management in the future electricity system?
Development in the electricity system related to demand-side management	What are the current barriers to demand-side management in the electricity market? (measuring equipment/financial barriers and legislation/market design) Which specific initiatives are currently carried out to promote demand-side management? Which future steps need to be taken to remove the barriers to demand-side management in the electricity market? Which electricity market is most appropriate for implementing demand-side management? How can demand-side management be bid into these markets? What is the development in the retail market towards promoting more demand response?
Settlement of electricity	How is the settlement for consumers of different sizes? How must the settlement be modified to allow for demand-side management for non-large consumers?

Category	Interview question
The role of the aggregator	Do you see individual units performing demand-side management in the future, or will an aggregator undertake this service? Who could potentially undertake the role of being an aggregator? (third party/independent player or established market player?) How should the implementation of aggregation be financed? Will aggregated demand-side management cause any negative consequences? If any, which?
Flexible consumption units	Which consumption units can be used for aggregation? How can these consumers be motivated towards providing demand response? Do you have an estimate of how much flexible consumption is available in your portfolio of consumers?

8.4.3 Results and discussion

Regulation and policies

Presently, it is challenging to add flexibility to the energy system since the security of supply is high in both Denmark and Austria. It is desirable to maintain the security of supply both for the citizens, but also because this attracts a lot of companies from outside Denmark who needs a stable connection, e.g. data centres. A way to ensure the stable supply in the future energy system is by controlling the demand in such a way that it matches the supply. The end user should thereby decide themselves whether they are willing to make their consumption rely on the supply.

The rollout of smart meters has the potential to influence end users and a change in their consumption patterns. In both Denmark and Austria, the rollout of smart meters is initiated. Denmark expects that smart meters will be fully implemented in 2020. In Austria, it is expected that the rollout will cover 95% by 2020. The rollout of smart meters means that the amount of data will increase and software which can handle this is needed along with an increasing amount of control of the data. The amount of data is not the only problem that smart meters can cause. Even when the deadline for the rollout of the Danish smart meters is fixed, it is still not known whether PV owners can be included in the flexible settlement.

Currently, Danish PV owners pay the differences between their annual electricity consumption and generated electricity by PVs, because the DataHub cannot handle negative consumption. Negative consumption means that PVs produce more electricity in one hour than the consumption in the same hour. Normally PVs owners produce more than what they consume in the summer and consume more during the winter. It is the Danish TSO who controls how many consumers can be switched to flexible settlement and how many are settled with standard load profiles in a grid area. The energy flexibility market needs to be regulated and standardized before stakeholders can access and participate the market.

Tariffs and taxes

One large barrier to energy flexibility is the profit for the end user. An electricity price reflecting the market price rather than the regulated price gives an incentive for buildings to perform flexibly because the price will be more fluctuating. It is thereby possible to achieve savings by shifting energy use to periods when prices are low.

Denmark is known as a country with high taxes, this also includes the taxes on electricity. In Denmark, 68% of the overall electricity price is from taxes and levies, and only 13% of the price is for the electricity and supply, the remaining are network costs. Compared with the average electricity price for households in the EU, the Danish electricity price is one third larger. The Austrian electricity price for households is almost equal to the EU average and the allocation between electricity and supply, network costs, taxes and levies are almost one third each. The Austrian electricity price for households, therefore, better reflects the market price compared to the Danish electricity price.

A mentioned in Case 1 – Energy consultancy in the Danish energy flexible buildings, the PSO tax will be removed from the electricity price in 2022. Furthermore, the Danish government wants to reduce the electricity levy by almost one third. Fjernvarme Fyn states that both incentives reduce the electricity price and create an incentive for the electrification based on renewable energy. An electricity price showing the market price rather than the regulated price gives the incentive to introduce energy flexibility for building owners because the price will be more fluctuating compared to what is experienced when the price is regulated. Different settlement models designed to promote demand response will be needed to make it a profitable business. Making the settlement vary due to the production of electricity creates an incentive for reducing consumption in times with low supply and increase consumption in times with high production.

An electricity system based on renewable resources creates a low spot price for electricity, it means that it is hard to create an incentive for consumers to perform demand response, this can be changed by more extreme prices on the spot market: "If the electricity price would be twice as high as it is today, then the potential would be much more significant." says Energie AG. Together with a variating tariff model, both at transmission and distribution levels, this will reflect the grid situation in the market and create a market-based electricity price. These tariff models will probably be designed based upon peak and off-peak periods like the current Austrian tariff model. The only network company that is doing something similar in Denmark, is the Danish network company Radius, who have split their tariffs into three parts depending on the time of use. It will not be possible to use the same model on the transmission tariffs since there are no capacity problems on the Danish transmission grid. The permission for such method change is given by the Danish National Regulating Authority NRA, (Energitilsynet), to each distribution and transmission company individually, and the process time can be up to a year.

Market condition and aggregators

The rollout of smart meters is an important step in the right direction if energy flexibility in buildings is to be realized. Devices which make it automatic and easy for the building manager to control the building due to the energy price and grid situation are required. Introducing energy flexibility would be very difficult in domestic building and smaller commercial facilities without some form of automation. The customer needs to know about the prize variation in an easy way, so they do not need to find the prices themselves. It is a bit different for large companies and industries since they have the possibility to save money by controlling their demand due to the supply. This can be controlled by an aggregator who delivers the service of control and optimize the energy usage in a building, or it can be controlled by a building manager for each individual building.

Energi Fyn believes that many BRPs do not want to have customer contact and because of that do not want to act as an aggregator for demand response. A lot of BRPs have electricity suppliers under them, who have customer contact. The BRP do not use time on the communication with customers. As the roles are divided right now, an electricity supplier will be most suitable for acting as an aggregator since they already have the customer contact. However, it could be a third-party as well, but then the third-party need an electricity supplier as a subcontractor who has the contact with the BRP. Existing legislation states that it can only be an electricity supplier who delivers electricity to the end consumer; this needs to be changed in the market requirement if a third-party aggregator should be able to deliver electricity to the end user without an electricity supplier.

Stakeholders’ collaboration

Stakeholder collaboration and role definition of stakeholders are important to make energy flexibility in buildings a reality. The large industrial companies already are flexibly settled, which means that they are not necessarily interested. To reach smaller consumers, new potential for load shifting at that end of the market needs to be identified. This will include buildings which have been traditionally settled by a standard load profile, but that could now be flexibly settled with the rollout of smart meters. The electricity supplier is the first actor that could help the customers by providing price signals.

Aggregators are needed because the private customers are too small to enter the regulation market, but if they are pooled they can potentially influence the market. The permission to get data can be a problem and the amount of data in the system when the smart meters are installed is massive and need to be handled in an optimal way. An electricity supplier needs permission from the consumer to get their data and the same is valid for a future aggregator. This makes the work with energy flexibility more difficult because the consumer needs to give this permission by their Danish NemID[4] before the stakeholders can process the data which are a need for energy flexibility in buildings to be an automatic in practice in Demark.

Collaboration between stakeholders in the market is important to achieve the common goal of making energy flexibility a great success in the future energy market, with more renewable energy resources and electrification.

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[4] NemID is a common secure login on the Internet, whether you are doing your online banking, finding out information from the public authorities or engaging with one of the many businesses that use NemID.

8.5 Conclusions

Two cases in this section discuss the role of energy consultancy and analytics in energy flexible buildings. The results show that there are four important aspects of the readiness of energy flexible buildings: Regulation and policies, energy price, market conditions and the collaboration between stakeholders.

Both Danish and Austrian market conditions need to be changed to further promote the implementation of energy flexible building. Smaller consumers can be motivated to provide energy flexibility if the regulation and legislation can be supportive.

Energy price is an important factor for the integration of energy flexible buildings. In the current Danish electricity price structure, the wholesale price is low, but the tariffs and taxes make up a large proportion of the electricity price. To create incentives for consumers to provide flexibility, the price needs to reflect the grid conditions instead of a fixed price.

Market conditions are an essential factor in the adoption of energy flexible buildings. Market access and data access need to be easy both for third-parties but also for smaller consumers. Meanwhile, the definition of roles and responsibilities also need to be clarified to encourage participation. Collaboration between different market players is important to achieve the range of potenitial benefits from flexible energy use.

9. The National Regulatory Authority

9.1 Introduction

The role of the National Regulatory Authority (NRA) is to make sure that the market is fair and clear for all market players. They regulate the market in an aim to provide the best economic conditions and competitive opportunities. The transition of the energy sector to integrate more renewable energy sources, leads to challenges and opportunities in the energy market. The NRA makes sure there are opportunities for stakeholders to participate in the market and solve these challenges.

This section introduces a comparative study of the Danish and Austrian national regulatory authorities to investigate their participation and opinions regarding the energy flexible buildings.

Table 9.1 Summary of data collection and results.

Purpose	Methodology	Targeted aspect	Result highlight
The National Regulatory Authority	Interviews	Opportunities Tariffs Market condition The potential for energy flexibility	• Consider the energy sources used in the grid to analyses the potential and need for energy flexibility. • Even when it is possible to control the energy sources and the need for energy flexibility are small, it still will create more competition in the market – which are good. • Blockchain can be used for energy flexibility instead of aggregators. • The rollout of smart meters makes real-time pricing possible. • Different tariffs due to the time of use create prices reflecting the grid condition and create an incentive to move consumption. • Easy access for smaller loads to be used as ancillary services is necessary. • Privet customers need a service provider to control and perform energy flexibility for them. It needs to be easy.

9.2 Background

The European Union set up directives for the energy sector with aims to lower the CO_2 emissions. A directive is a legislative act that sets out goals that the member countries must achieve. Each country decides how to reach these goals. Some examples could be the Renewable Energy Directive which requires the EU to fulfil at least 20 % of its total energy needs with renewables by 2020 or the Energy Efficiency Directive helping to reach the 20 % energy efficiency target by 2020 (Danish Energy Agency, 2015).

Each member country is required to abide by the directives and control the market conditions and methods used for price setting and grid operation. The regulators are responsible for strengthening the competition and ensuring that this does not compromise the security of supply and sustainability.

Energy flexibility in buildings are one of the key elements that will help the end-consumers to participate in the energy markets. The National Regulatory Authority is responsible for creating a fair market for all stakeholders, both existing and new ones who want to enter the market. They aim to ensure that the market is transparent for all customers, and that the methods which are used for the settlement of energy prices are consistent with the laws in force. All in all, they make sure that the energy market is competitive and that the customers are treated well and equally.

9.3 Case 1 – The National Regulatory Authority in the Danish and Austrian energy market

9.3.1 Introduction

This case is from the same source as in 'case 5.1 – Aggregators'. (Schultz and Friis, 2018) The aim was to investigate the motivation and barriers for aggregated demand response in Denmark and Austria by conducting interviews with electricity suppliers, district heating supplier, distribution system operator, energy service companies, experts in energy, and system regulators. This section introduces the national regulatory authority regarding energy flexible buildings.

9.3.2 Methodology

This project adopts the qualitative methodology of interviewing to examine and report the experience acquired by national regulatory authorities. Two interviews, one with the Danish NRA Energitilsynet, and one with the Austrian NRA E-Control is conducted as semi-structured face-to-face interviews with experts in energy flexibility. Both organisations had great knowledge about the situation of energy flexibility in their country. The interview questions are shown in Table 9.2.

Table 9.2 Interview content.

Category	Interview question
Future energy system	Which solutions must be implemented in the future electricity system, when more volatile renewable energy sources are installed, to maintain the security of supply and competitiveness in the market? How does the transition of the electricity system affect your company? How can these barriers be removed? And how can we create incentives instead?
Demand response barriers and initiatives	What are the current barriers for demand response in the electricity market? Which specific initiatives are currently carried out to promote demand response? Which future steps need to be taken to remove the barriers for demand response in the electricity market? How can demand response be bid into these markets?
Settlement of electricity	How is the settlement for consumers of different sizes? How must the settlement be modified to allow for demand-side management for non-large consumers?

Category	Interview question
The role of the aggregator	Do you see individual units performing demand-side management in the future, or will an aggregator undertake this service? Which market players have an influence on the regulatory implementation process for aggregators?

9.3.3 *Results and discussion*

Opportunities, motivation, and barriers to energy flexibility

Denmark and Austria have different electricity generation sources. AT present, Denmark depends partly on wind energy, which is fluctuating due to the weather, and does not have a natural storage facility inside the country. If the electricity from the wind needs to be stored, it must be stored in batteries or converted to gas or heat and then stored in this state. Otherwise, it can be sold to Norway who have the capability to store electricity in pumped hydro and then produce electricity again when needed. Austria has the possibility to store the electricity, which they mainly produce from hydropower, in pumped hydro. This means that they can store and generate electricity easily when needed and thereby do not have the same need for energy flexibility as Denmark has since the hydropower gives flexibility itself. E-Control still agrees that energy flexibility is needed in the market to create competition between different methods, which are good for the market. The market will control itself if the conditions allow for different technologies and methods. The market structure will thereby show if there is a business case for energy flexibility in buildings.

The market structure is designed to be open to all market players. The only barrier for energy flexibility in buildings is the economy and capacity limitation in the electricity market. This can be solved by introducing the role of an aggregator to the market. Either as a new market player or an existing one undertaking this role. An aggregator makes the flexibility convenient for the customers and pool loads is such a way that the capacity limitation for participation in the electricity market is obeyed. By doing this the aggregator, and thereby energy flexibility in buildings, has the chance to compete against power plants.

Another interesting subject related to energy flexibility is the use of ’Blockchain’ in the electricity system. The most well-known conceptualized case of Blockchain is cryptocurrencies such as Bitcoin. This is mentioned by the Austrian NRA, which can play a major role in the future electricity system. It facilitates automatic and direct trade of electricity between consumers and producers, which is ideal for energy flexibility in buildings. However, introducing Blockchain in the value chain of the electricity system will rearrange the business ecosystem completely; all intermediaries between producer and consumer will be excluded and their function will be carried out by software. Electricity trade will become frictionless and transaction costs will be lowered considerably while the business ecosystem will become simpler in case of buying and selling electricity.

The National Regulatory Authority preferences and concerns regarding energy flexibility in buildings

The energy market needs to be regulated at all the time to ensure the customers and stakeholders a fair and safe market space. The methods which are used for settlement for energy can differ from retailer to retailer, but the methods must be approved by the NRA before being valid. This means that the NRA themselves do not decide how the tariff model should be structured, they just approve it, if it agrees with the current laws and regulations.

In both countries, the rollout of smart meters has been started. This makes it possible to move from a standard load profile structure to a new structure with different tariffs and real-time pricing. Different methods for electricity tariffs are already seen in both the Danish and Austrian market. A tariff model depending on the time of use are well-integrated in the Austrian system, where a day is split into parts depending on peak and off-peak periods which creates an electricity price reflecting the real market conditions. Another way for making the electricity price more fluctuating is by introducing interruptible tariffs by allowing the DSO or TSO to disconnect the customer from the grid if there is a lack of electricity in the grid. This system already exists in Austria, but E-Control still means that it needs to be further developed for energy flexibility. Such a system can be seen as a two plugs model where customers agree that if there is a shortage of electricity in the grid, they do not need electricity to the second plug-in and receive in return a lower tariff. It is thereby easier to control which demands are switched off instead of it is an entire town or part of a country that will have problems in case of shortage or line damages. It is a big effort for the DSO to run such a system and not all DSO has the resources to integrate it into their business model. A way to overcome this and make it possible for all customers to get their consumption interruptible is by making it political regulated. All tariff models need to be approved by the NRA.

Market conditions

In Denmark, real-time pricing is possible if the supplier offers this service. This gives the customers an opportunity to participate in the Nordic spot market – Energy flexibility is however still hard to implement in the market. Electricity suppliers can become an aggregator, or they can outsource this service. To be a third-party independent aggregator, the company needs to register as a BRP or be in a contractual relationship with one. Aggregators need permission from the electricity supplier to aggregate loads and can consequently only pool loads with a given supplier. This limits the size of the pool. A market player needs to be prequalified by the TSO to operate in the market. An aggregated pool will be treated as a single unit, which increases the potential in the market for the joint unit. Even though it is legally possible to perform aggregation in Denmark, important competition issues between aggregators and BRPs/suppliers are present due to lack of clarity of roles and responsibilities. The ancillary service market is mainly designed for generation units, e.g. the requirement of having an online metering system increases the cost for the energy flexibility service. The primary reserve is automatically operated, which means that the delivery time is very short, and the frequent activation can be an issue for most energy flexible units. Most of the secondary reserve in Denmark is covered by Norway, and the entry opportunities in this market are therefore small. Both primary and secondary reserves require symmetrical bids, which is a barrier for energy flexibility since consumers rarely generate and consume in equal measure. The tertiary market is manually operated, which means that participation in this market needs a control centre operation 24/7. This is a huge cost barrier.

In Austria, aggregators already exist in the balancing market. In the wholesale market, no aggregators are seen yet, though demand response could access the European Power Exchange (EPEX) day-ahead market by the principal. The individual load in an aggregator pool must be prequalified separately for each consumer, which makes the process inconvenient. Furthermore, all consumers need to install an expensive dedicated phone line to participate in the balancing market (Bertoldi et al., 2016). All this increases the cost for each consumer's participation, and the process leads to a reduction of the pool size. An independent third-party aggregator needs to be contracted with the BRP/supplier. As the Danish primary reserve, the participants in the Austrian primary reserve market need a fast delivery time and symmetric bids, which makes consumer participation difficult. The secondary reserve market is best suited for energy flexibility since the primary control is covered through cross-border cooperation between European countries. The secondary control is often enough for stabilizing and there is no need for tertiary control. The secondary market allows for asymmetric bids and a weekly auction-based market structure split into three-time windows, with a duration up to 4 hours, which allows the aggregator to bid into the time window appropriate for them. But at the same time, it adds a barrier for demand response since a four-hour availability is required.

The potential for energy flexibility

The potential for energy flexibility performed by devices like PVs, batteries, electric vehicles and heat pumps is high since such devices are having a storage opportunity and a relatively high capacity compared to TVs and private refrigerators. Both NRAs agrees that an aggregator is needed if private customers should deliver energy flexibility since they are not willing to put effort into it themselves. Office or industrial buildings, on the other hand, might have the capability to perform energy flexibility themselves, but by pooling their loads with other loads the effect might get higher.

9.4 Conclusion

The results of the case study show that both Denmark and Austria allow energy flexibility in the grid, but the Austrian electricity tariff models creates more incentives. The Danish tariffs are fixed, and the Austrian tariff variates due to the time of use and reflects the market/grid situation. The Austrian electricity system also adapts interruptible tariffs where the DSOs or TSOs can interrupt the grid connection if a shortage occurs. In return, consumers have reduced grid tariffs.

The potentials for energy flexibility also depend on whether there is a need in the grid. The Austrian geography of mountains and rivers creates great opportunities for hydroelectricity production and storage facilities. In Denmark, there is a long coastline and flatland which are suitable for wind energy, but the storage of the excess electricity is still an issue. Therefore, energy flexibility from buildings are needed and can be used to stabilize the grid. Some market changes like shorter time duration for the biding periods in the ancillary service market, lower minimum bid size and asymmetric bids can increase the business opportunities for energy flexibility and make it much easier for buildings to enter the market.

10. Industrial consumers in Energy Flexible Buildings

10.1 Introduction

Industrial consumers are important stakeholders in relation to energy flexible buildings. Industrial consumers include industries like commercial growers, cooling, breweries, and factories. This section will elaborate their role in energy flexible buildings and how they are utilized in Denmark.

Four case studies with the above-mentioned industries have been conducted to investigate the participation of the various industries and their opinions towards energy flexible buildings.

Table 10.1 Summary of data collection and results

Purpose	Type of Building	Methodology	Targeted aspect	Result highlight
Building-to-Grid participation	Industrial	Interview	Regulation and policies Market conditions Energy prices Smart grid solutions	• Self-production of heat and some electricity, making them sensitive to changing electricity prices if flexibility cannot be achieved. • Not familiar to smart grid solutions, but positive towards net-based services if profit is maintained.
Acceptance of smart solutions	Industrial	Interview	Energy transformation Shared support interaction Energy flexibility Smart grid solutions	• Electricity prices may vary in the future, making it crucial to have access to Nord Pool spot prices. • Heat from the cooling process is utilized to cover own heat consumption. • Do not proactively seek involvement in smart grid activities. • The desire to brand the company as “green”. It impacts the inscription stage but interconnects customer focus.

10.2 Background

The existing method of electricity generation has highly contributed to greenhouse gas emission and climate change (Sutanto, March 2011, Samad and Kiliccote, 2012). The emergent need for transformation of the electricity industry is recognized worldwide (Sutanto, March 2011). In order to ensure the transformation in the energy sector of member states, the European Union has in 2012 adopted the Energy Efficiency Directive (European Environment Agency (EEA), 2013). The directive’s primary goal is to ensure a reduction in energy consumption of the member states by 20 % by 2020, which in turn will help to reduce carbon emissions (European Environment Agency (EEA), 2013).

The literature indicates that the concept of smart grids has been explored to establish a foundation for the development of future energy systems (Samad and Kiliccote, 2012, Dansk Energi and Energinet.dk, 2010). Smart grid has been recognized as the most effective and economical solution on the path to a future energy system that is independent from fossil fuel energy sources (Dansk Energi and Energinet.dk, 2010). Moreover, it requires innovation in electricity production, management and use (Mickoleit, 2012).

The smart grid functionality depends on collaboration and integration of different stakeholders, adoption of new technologies, regulations and business models (Samad and Kiliccote, 2012, Heiskanen and Matschoss, 2011, Gungor et al., 2011, Vukojevic and Milošević, 2010). However, an active consumer participation in smart grids is crucial for their success (Palensky and Dietrich, 2011, Liu et al., 2011, Rahnama et al., 2013, Verbong et al., 2013). The recent studies on electricity consumption emphasize the importance of consumers as energy co-providers in smart grids (Geelen et al., 2013). Active consumer involvement in electricity networks refers to the concept of consumer engagement (Gangale et al., 2013) and demand response management. Moreover, the existing literature indicates the importance of end-user communities for truly smart grids to become a reality (Samad and Kiliccote, 2012, European Environment Agency (EEA), 2013, Mengolini and Vasilevska, 2013).

The resent research regarding consumers' adoption of smart grid concepts reveals consumers' positive attitude toward smart grid technologies (Wolsink, 2012, Giordano et al., 2013, Dedrick and Zheng, June 2011, Samad and Kiliccote, 2012). Yet, there are still many issues regarding consumers' needs that must be addressed in order to achieve consumers’ participation and acceptance (Giordano et al., 2013). Meanwhile, the consumer management in a smart grid is challengeable due to a high variation of consumers' preferences, interests and supplied amount of energy to the grid (Rathnayaka et al., 2012). Giordano et al. (2013) emphasize that: "Consumers, their daily routines and the social context in which they operate, should be more central in the smart grid community, where the focus is still mainly on technological issues and economic incentive". Therefore understanding consumers' needs and behaviour in smart grids is essential as it lies at the foundation of the EU energy market design (CEER (Council of European Energy Regulators), 2014).

The customers of a smart grid are divided by Samad and Kiliccote (2012) in to the following categories: 1) residential, 2) commercial (i.e., buildings and multi-building facilities), and 3) industrial. The participation of industrial consumers in smart grids is important due to their consumption footprint, heavy peak energy use and complexity in smart grid technologies implementation (Samad and Kiliccote, 2012). Thus, active involvement of industrial consumers in the development of smart grid solutions is important to ensure transformation to the future energy system.

Despite the importance of industrial consumers having been identified, empirical studies of smart grids mainly address the residential consumer sector (Samad and Kiliccote, 2012, Gangale et al., 2013). Very few focus on industrial consumers/communities’ involvement or their contribution to the development and adoption of smart grid solutions (Samad and Kiliccote, 2012, European Environment Agency (EEA), 2013).

10.3 Case 1 – Business opportunities for Building-to-Grid

10.3.1 Introduction

This case is part of the same project as ‘case -building managers in energy flexible campus buildings’ (in Chapter 3). The project aims to investigate the motivation and barriers for the energy flexibility in industries by conducting interviews with commercial growers and breweries.

This section introduces the industries’ opinions regarding the energy flexible buildings (Jespersen et al., 2017)

10.3.2 Methodology

The qualitative methodology of interviewing is adopted in this case to examine and report the experience acquired by various stakeholders involved in the case study, specifically their reflection on energy flexible buildings from their own perspectives. Qualitative research methodology is popularly adopted when investigating new fields of study or ascertaining prominent issues (Corbin and Strauss, 2008).

The interviews were conducted as semi-structured face-to-face with the financial managers of the commercial grower Alfred Peterson & Søn (AP) and the technical manager of the brewery Vestfyen A/S. Alfred Pedersen & Søn ApS (AP) is a horticulture company situated just outside Odense, Denmark. The company specializes in producing tomatoes, cucumbers and bell peppers. The products are sold throughout the country as high-quality brands. The brewery Vestfyen A/S (BV) is a brewery located in Assens, Denmark. The brewery produces beer and beverages. In a very competitive market, BV is able to market their own brands of beer and sodas along with an extensive private label production for a retail chain, COOP. The primary products are in the budget range. Questions used for the interviews can be seen in Table 10.2.

10.3.3 Results and discussion

Energy services

To produce vegetables such as tomatoes in Denmark, it is necessary to add a certain amount of heat, artificial light, and CO_2 for the growing process to succeed. AP has their own gas-fired combined heat and power plant (CHP), which is fully automated. This makes AP self-sufficient in terms of heat, electricity, and CO_2 for the production. AP utilizes the services of Danske Commodities, which is an energy trading company, in order to operate the CHP and sell electricity to the Nord Pool Spot market for optimal economic results.

Table 10.2 Interview questions for the commercial growers concerning electricity consumption and energy flexible buildings.

Category	Interview questions
Electricity consumption	Who is your electricity supplier and how is your cooperation? Who is your heat supplier and how is your cooperation? What is the annual energy consumption of the company (electricity and heat)? Considering your primary production processes, which are then the most energy consuming and which of these are primarily electrically operated? Any other energy demanding processes that supports the operation of the company? How is the company's energy consumption pattern characterized? Currently, how do you control your energy consumption (manually or automated)? Can you describe the environmental strategy of the company and the current initiatives?
Knowledge of smart grid solutions	What do you know about flexible electricity consumption, electricity regulation, and smart grid? In your company, which types of processes do you consider as relevant and attractive to the smart grid approach? To optimize (minimize) the energy expenses, which future initiatives are then planned? (If any?) What barriers do the company consider related to participation in programs where the consumption of electricity is partly controlled by an electricity supplier? What incentives would do it attractive for you to participate in network-based services like: • Hourly-priced electricity consumption • Interruptible electricity consumption

BV is self-sufficient in terms of high-temperature heat from a woodchip boiler. The boiler is operated to comply with the production planning. BV is located only a few kilometres from Assens Fjernvarme, which is a district heating (DH) supplier. Currently, it is not possible to supply DH at the temperature needed for the beer production. As a result, BV continues to operate their own boiler. It is possible for BV to activate a turbine for electricity production driven by the steam from the heat production, but this solution is considered as a backup only, which is not seen as economically profitable.

AP operates a hot water storage with the purpose of enabling flexibility for the CO_2 and electricity production, and to act as a back-up for the supply of heat to the greenhouses. BV does not use hot water storage.

Production methods

This category contains concepts that are related directly to the costs of producing primary or secondary products at AP or BV.

For good quality vegetables to be grown, it is important for AP to provide the correct environmental conditions in the greenhouses for the photosynthesis to occur. Fertilizer is added automatically along with heat, growing light, and CO_2. According to the financial manager at AP, the most energy demanding process at AP is the production of CO_2. It is primarily produced by the gas engines, which have the primary function of producing electricity. Heat can be supplied from the gas engine as a by-product or from the gas boiler. Heat may also be purchased from the district heating grid. During winter, growing light for the products is the second most energy demanding process. Other processes, such as packing and cooling, consume electricity as well. Currently, sales of electricity constitute the primary income for AP.

When brewing beer at BV, the wort stage is a very energy demanding process. Brews are heated through several steps in the production. Half of the heat production from the woodchip boiler is used by the brewing process. The other half is used to clean glass bottles. Both processes are continuous. The primary demand for electricity comes from the production of plastic bottles for soda beverages. Each bottle is formed from a plastic tub, which is then heated and expanded into a mold using compressed air. Half of the electricity demand from the brewery is used in this process. A significant part of electricity, equal to 15 %, is used for cooling the tanks during fermentation of the beer. The fermentation process takes almost three weeks, depending on the brew of concern. BV is self-sufficient in terms of heat. Electricity is purchased from a supplier.

When comparing the production methods for AP and BV, it is interesting to notice the source of heat. BV will produce the heat required for the processes as a single purpose. AP will produce heat as a by-product from other processes. AP optimize the energy production of electricity, heat, and CO_2, while BV only needs to optimize production of heat, considering energy.

Energy supplier

Currently, AP and BV are supplied by electricity from the same supplier, Energi Danmark. AP signs contracts for 2 years at a time. The mix of spot market electricity versus fixed price electricity depends on a risk assessment upon signing the contract. Common splits of spot vs fixed price are mentioned in Table 9.3. Even if AP is self-sufficient, they will still purchase electricity in the electricity market.

Table 9.3 Energy supplier for AP and BV, including sourcing strategy examples.

Category	Nursery Alfred Pedersen & Søn ApS (AP)	The brewery Vestfyen A/S (BV)
Energy supplier	Energi Danmark Fjernvarme Fyn Year contracts 2 years Risk assessment of the electricity market. 50% spot/ 50% fixed price	Energi Danmark Fixed price with a surcharge for use profile The CFD (transmission in the grid) is purchased on the spot market

Business model

The AP business model is a combination of producing tomatoes, cucumbers, bell peppers and electricity. The primary source of income is electricity from the operation of a CHP plant with 9 MW of turbine capacity.

AP has a high degree of freedom in relation to electricity production. They are not familiar with the concept of smart grids or flexible energy consumption. Given the investments in the CHP, AP has no plans participationm in net-based services. However, the conditions for entering such an agreement would be to maintain profitability in the electricity production and production from the greenhouses. A strong incentive for AP to investigate the potential for energy flexibility comes from the cancellation of the subsidy to decentralized CHP plants at the end of 2018.

Focusing only on the production of beer and beverages at BV, the operation of the brewery is optimized to be very cost effective. A new brew of beer is started in a tank every 3rd hour. Consequently, the existing brews are shifted to the next production step. The production of plastic bottles runs during the day and is continuously optimized. The process has a lot of surplus heat from the process, but BV is not able to use the heat in other processes due to taxes.

During the interview, BV demonstrated extensive knowledge of flexible energy usage, but they are not familiar with the particulars of smart grids. The best candidate for a process which can be shifted in time is the plastic bottle production. To do so, it is necessary to store the bottles for shifted use. It has not been possible to find a profitable storage solution considering the savings in shifting the production. Another candidate process for time shifting is the cooling process for the fermenting tanks. Depending on the recipe, it is possible to stop the cooling process for several hours, without causing impacts on the product. However, not all recipes tolerate a lack of cooling. Implementing demand response would be restricted by operation of the fermentation cooling process on a shifted basis.

The smart grid concept is not familiar to either BV or AP, but flexible energy consumption has been considered. Both companies are positive towards net-based services as long as profitability is maintained. AP and BV have invested in heat-producing units to support the production. This decision is currently a necessity for BV, in regard to steam production. AP has invested in a CHP thereby introducing electricity as a product to the portfolio. BV is likewise able to produce electricity, but the electricity demand profile does not support a steady operation for the turbine. The product line at AP reflects quality for the high-end market. The CHP is branded as environmentally friendly on the website, even though it is fueled by gas. BV may have an anonymous appearance but is marketed as Denmark's 4th largest brewery. The bulk of the production is a private label for budget retail chains. Actually, BV has an environmentally friendly heat production, as the boiler is fueled by woodchips.

Environmental strategy

Environmental strategies usually concern the company's efforts in recycling material, constrain unnecessary water usage and reduce energy consumption produced on fossil fuels. In other words, activities that relate to climate change.

AP has a unique opportunity as the vegetables they produce require CO_2 for the photosynthesis to grow. As a result, AP will continuously produce CO_2 from the gas engine, with heat and electricity as by-products. It is not a fossil free production, but it is the next best thing in a climate change context.

Further investments at AP are related to LED light sources and investigations into heat pumps have been undertaken.

BV is not able to use the fossil free district heating from Assens Fjernvarme due to temperature limitations. Instead, BV produces heat and steam from a woodchip boiler. BV continuously optimizes operations with new pumps, ventilation replacements, and process redesign to lower energy consumption. For BV, the optimization activities are a competitive advantage rather than a marketing strategy. Given that the bulk production at BV is for budget retail chains, the customer concern is focused on cost rather than climate change.

10.4 Case 2 – Industrial consumers’ acceptance of smart grid solutions

10.4.1 Introduction

This case is adapted from (Ma et al., 2018). The aim is to investigate the possible participation of industrial consumers in the demand response by conducting interviews with cooling and factory industries in Denmark.

10.4.2 Methodology

This section adopts the qualitative methodology of interviewing to investigate the experience acquired by various stakeholders. Seven in-depth interviews have been conducted with selected companies as semi-structured open interviews (Breakwell, 1995) which are appropriate to apply in cases studies with limited knowledge. The interview guide is developed based on the generated literature review and modified Information Communication Technology (ICT) adoption model by Chinedu Eze et al. (2014). The interview guide is altered in the process to the company's specific context. Meanwhile, the main interviews’ content remains the same. The interviews lasted for approximately 60-90 minutes and were recorded and used later for transcription.

Table 10.4 Interview questions in case- Industrial consumers’ acceptance of smart grid solutions.

Category	Interview questions
Involvement in the transformation of the energy system in Denmark	Are you aware of energy system transition in Denmark? How the transition influences you? How the company is involved in the energy transition? What feedback on energy consumption do you prefer? How did you find out about Smart Grid Living Lab (LB)?
Interaction regarding Shared support	How did you collaborate with LB? How do you receive/exchange information from/with LB?

	Why did you collaborate with LB? (e.g. organizational belief, management system, government, previous pattern of IT-use, expectations about new tech. etc.) Why /How do you collaborate with other companies? Challenges? Benefits? Concerns? How do you exchange information with the other companies? What information is it?
ICT Platform, Equipment, Device	Did you acquire new ICT equipment? (e.g. smart meters) Why is that? What did it change compare to the previous manner? (What's new?) What are the challenges concerning new equipment? (Choice, analysis of solutions, integration etc.) Any requirements? What do you think about the old equipment? Is it good enough? How it helped you to change? (Compatibility between new and old equipment). What changed after the equipment was installed?
Regarding Openness to change, Trust, Safety, and Security	Do you have any trust issues? Are there any issues with the new equipment?
Regarding Return on investment, Adoption cost	Does new ICT contribute to continued improvement/ROI? How? Challenges? Who does pay for transformation? What costs associated with ICT adoption? (training of employees)
Policy and motivations (EU and Danish regulations and policies)	What regulations/policies influence the company? How regulations influence the company?
Energy Flexibility	Can you offer a particular type of flexibility? What can motivate you toward flexibility? What will be changing in your business with a change in flexibility? (Business model? communication with others?) Benefits? Difficulties? Costs? Concerns?
Community	To motivate consumers, there is a suggestion to organize the industries in communities. What do you think about it? (Good or bad idea?) How do you think companies can be organized in communities? How the communities will function/work? How to motivate them? What challenges will there be?

10.4.3 Results and discussion

Awareness of multiple contexts

According to Eze et al. (2012): "Awareness of multiple contexts is the ability to take into account all options available and to ensure that the impending challenges are thoroughly evaluated". Eze et al. (2012) argue that awareness of multiple contexts affects the initial stage of the smart grid adoption. However, the result shows that the awareness of multiple contexts also affects the later stages (both inscription and stabilization stages).

Awareness of multiple contexts refers not only to consumer awareness of a single ICT adoption, but also to all emerging situations and stakeholders that confine new ICT adoption (Eze et al., 2012). The EU commission has indicated the importance of energy consumers’ awareness for the initiation of smart grid deployment (European Commission, 2017). Wider recognition of smart grid, flexible consumption and demand response concepts by electricity consumers are necessary to trigger the transition to the future intelligent el-net (Danish Ministry of Climate Energy and Building., 2011). Generally, the escalation of consumers' smart grid knowledge and awareness are required to enhance consumer engagement with smart grids (Eze et al., 2012). Nevertheless, the limited consumer knowledge of confidence and choice for new systems diminishes the potential benefits of smart grid applications (European Commission, 2010).

Consumers' knowledge and awareness can be enhanced via educational and informational campaigns (Danish Ministry of Climate Energy and Building., 2011). Also, feedback on energy consumption helps to raise industrial consumers’ energy awareness, and can be divided into four categories: direct feedback, indirect feedback, inadvertent feedback, and energy audits (European Environment Agency (EEA), 2013). The type of feedback has a major impact on energy-awareness and consumers’ attitudes toward energy consumption (European Environment Agency (EEA), 2013). Meanwhile, some feedback measurements can be activated after smart meter implementation, such as availability of real-time pricing.

Shared support

Shared support refers to open participation and collaboration across stakeholders. It determines the realization of stakeholders' shared goals. For example, in Denmark, the electricity industry is responsible for the initiation and coordination of the shared roadmap for smart grid deployment and continuous development (Danish Ministry of Climate Energy and Building., 2011). Meanwhile, research institutions, commercial companies, big industrial players and authorities are also highly responsible for different tasks regarding smart grid deployment (Danish Ministry of Climate Energy and Building., 2011). In Denmark, there is close collaboration across research institutions and firms for the ICT development regarding communication, electronics, wireless technology, control technology, embedded systems and software (Troi et al.). The open standards and communication in the Danish future smart grid model, not only mitigates the consumers’ dependence on a particular producer, but also promotes innovative solutions (Danish Ministry of Climate Energy and Building., 2011).

According to (Eze et al., 2012), shared support is recognized at the translation, framing and stabilization stages. However, the result shows that shared support mainly influences the translation stage. Moreover, shared support ensures industrial consumers continuously participate in the adoption process (i.e., further translation to the framing stage). The case studies reveal that industrial consumers do not proactively seek involvement in smart grid activities. Thus, a key actor should actively presume and involve the industrial consumers (e.g. demand response). Despite collaboration with network actors being driven by the interviewed companies' commercial interest, Claus Sørensen A/S aligns their interest with their partners. Meanwhile, the interest alignment at the translation stage ensures a stronger actor-network. The stronger network has a higher potential to realize the shared goal and establish the dominant technological standard.

Return on investment (ROI) and adoption cost

Smart grid deployment requires investment and development that concerns the entire electricity value chain, and especially within the electricity consumers' domain (Samad and Kiliccote, 2012). According to Farhangi (2010), ROI grows with the increasing functionality in smart grids. The existing literature indicates that the adoption rates of energy efficiency technologies by industrial consumers are higher in smart grid-related projects, with shorter payback time and lower costs (Anderson and Newell, 2004). Industrial consumers are especially concerned with the upfront costs rather than annual savings. The emerging ICT is unlikely to be adopted if it cannot generate ROI in a foreseen period. The ROI affects the early adoption stages due to the profit expectation.

One key factor that determines emerging ICT adoption is the initial investment cost (Eze et al., 2012). Consumers determine the adoption cost of technology by comparing the benefits and the additional cost of the emerging ICT use in companies (Chinedu Eze et al., 2014, Adner). For instance, the adoption cost of smart meters can be divided into the initial cost and on-going cost. The initial cost includes purchasing, installing and integrating costs, and the on-going cost includes data transmission, maintenance, training, billing and electricity costs. Therefore, DSOs (distribution system operators) usually own the smart meters and do the maintenance. The ROI and adoption cost have an impact at the inscription (evaluation and conceptualization of ICT), translation and stabilization stages. However, the adoption cost has especially an significant impact at the translation and stabilization stages. Stakeholders negotiate the price at the translation stage and further renegotiation at the stabilization stage.

Ease of use

Ease of use is defined as "... the capacity of the emerging ICT to allow people with limited knowledge or limited ICT skills to accomplish complex tasks" (Eze et al., 2012). This factor is applied to both individual and organizational ICT adoption (Park et al., 2014, European Environment Agency (EEA), 2013). Research focused on the residential consumer engagement in smart grids, indicates that several variables (e.g., understanding of smart grid, understanding of compatibility between existing technologies and emerging ICT) influence consumers' perception on ease of use and acceptance of a new system (Park et al., 2014). The limited smart grid understanding by consumers is, in part, due to the poor understanding of smart grid terminology (SGCC (Smart Grid Consumer Collaborative), 2010).

Eze et al. (2012) propose that the connectivity and compatibility between existing technologies and emerging ICTs determine the ICT integration. The connectivity is highly dependent on the availability of communication channels for all stakeholders (including electricity consumers) (Mickoleit, 2012). While, the compatibility relies on the similarity degree of the value and the way of use between existing and emerging technologies (Wu and Wang, 2005).

Ease of use influences the inscription, framing and stabilization stages (Eze et al., 2012). However, the result shows that the compatibility between existing technologies and emerging ICT appears at the framing stage (Eze et al., 2012). In the case of Claus Sørensen's A/S, at the framing stage, ease of use is the equipment requirement. The company's engineer points out: "We brainstorm together with GridManager. Sometimes we get the ideas when we work with equipment. It happens spontaneously. We provide feedback about the portal's functionality and contribute with the suggestions".

Flexibility and dynamic pricing

Flexibility affects the inscription stage due to the importance of flexibility awareness. However, flexibility has the main impact at the translation and framing stages, because the energy capacity optimization depends on stakeholders' negotiations (e.g., dynamic pricing) and actions (e.g., implementation of smart meters). Flexibility may impact the stabilization stage due to potential consumer management by load profiles (Wattjes et al., 2013). Meanwhile, dynamic pricing mainly affects the adoption process from the translation to stabilization stages.

The electricity retailer, TREFOR, points out that it is the retailers' responsibility to make consumers aware of the dynamic pricing options. This may motivate consumers to offer flexibility and lead to behavioural change. Furthermore, the project manager points out that the majority of industrial consumers adopt the Nord Pool spot price (the Nordic electricity wholesale market) option offered by TREFOR. It shows that dynamic pricing influences consumers. However, consumers have yet not received any benefit from choosing the spot-price option, because the spot price is calculated according to grid areas' average profile. The implementation of the wholesale model should ensure benifit for the individual consumers due to behavioural change.

The industrial consumer, Claus Sørensen A/S, emphasizes that electricity price may vary daily and hourly in the future. Thus, night hour electricity may not be the cheapest. Therefore, it is curial for companies to have access to the Nord Pool spot price. Moreover, the consumer portal could be more useful if it could be online and the data could be downloaded directly into the portal. At the same time, rules and regulations in the industry should be adjusted based on different smart grid requirements.

It is important to mention that Claus Sørensen A/S utilizes the heat removed from products in the cooling process to heat its own facilities. However, the company generates more heat that it can use. Meanwhile, the company does not have the possibility to sell the heat and this, in turn, hampers behavioural change. The company can in theory collaborate with neighbor companies for the heat sale, but this option is not available yet. The automatic control of equipment is important for Claus Sørensen A/S. However, it should also be possible for consumers to interfere with the load control process if it is necessary.

Energy tariff structure and liberalization

The structural shifts of the electricity industry are determined by ICT application. According to the EEA (European Environment Agency (EEA), 2013), there are two types of structural factors that impact upon consumer behaviour and engagement in the smart grid: liberalization and energy tariffs structure. For example, the liberalization of the energy retail market provides consumers with the possibility to switch energy retailers and offers (European Environment Agency (EEA), 2013). The Danish parliament passes a regulation regarding the electricity market liberalization that takes consumers as the focus (Energinet and Dansk Energi, 2012). This model implies a closer contact between electricity retailers and consumers in the retail market.

A number of tariff structure issues should be solved to ensure active consumer evolvement (European Environment Agency (EEA), 2013). For instance, a survey shows that large electricity consumers (with electricity consumption more than 100,000 kWh per year) do not move consumption along with the real-time electricity price, because the real-time price variation does not provide adequate incentives to change their behaviour (Danish Ministry of Climate Energy and Building, 2013). Thus, to motivate consumers to provide flexibility, the grid companies should consider the variable tariffs (Danish Ministry of Climate Energy and Building, 2013). At the same time, the alignment of the tariff structure in the value chain is required (e.g. between grid companies and electricity retailers), because the variety of the tariff structures can have a negative effect to the economic efficiency (European Environment Agency (EEA), 2013). The project manager at TREFOR emphasizes that the tariff structure should be adjusted, not only according to grid companies' and electricity retailers' needs, but also to consumers' needs.

The structural factor of energy market liberalization affects the inscription stage because it triggers smart grid transition. The factor also influences the translation stage because the continuous release of liberalization packages (Dansk Energi and Energinet.dk, 2010) has to be potentially translated by the network. Moreover, the energy tariff structure impacts the adoption process on the framing and stabilization stages due to technology alteration, consumer behaviour changes, and network change.

Customer focus and green image

Customer focus is a key factor that drives industrial consumers' engagement of the technology adoption. It triggers translation to the framing stage. Customer focus refers to the technological solutions (i.e., smart grid solution) that improve industrial consumers’ core processes and retain their customers, i.e. achievement of competitive advantage is a primary motivator for companies. Customer focus emphasizes that companies’ concern about their customers’ satisfaction and retention (Eze et al., 2012), and customers impact on companies’ decision making. Customer focus is a key factor that impacts on/drives industrial consumers' engagement at the inscription stage and continuous participation. A new factor that motivates Claus Sørensen A/S network participation is a desire to brand the company as a "green company". Branding as a "green company" impacts at the inscription stage. However, this factor also interconnects to customer focus.

Solution integration

Traditional smart grid solutions include only energy screening or solution development and implementation. This study reveals that industrial consumers prefer a one-stop smart grid solution/offering or an integrated solution provided/executed by one organization/supplier (rather than separation into several organizations). This a one-stop smart grid solution/offering that affects the inscription stage. The energy consulting company, Udvikling Fyn points out that consumers prefer a one-stop solution/offering rather than a separated energy screening and offering. Meanwhile, energy audits, advertisement, bandwagon, and grid companies' visits to the customers' sites can also enhance consumer awareness of energy conservation.

Service quality and process improvement

Quality of Service (QoS) is defined by as the "...capability of emerging ICT to deliver efficient results to end-users." and also refers to the ICT possibility to improve companies' (i.e., energy consumer) processes, profit and deliver services at reduced costs (Eze et al., 2012). Eze et al. (2012) argue that poor service quality can negatively affect the adoption process. Service quality can also be defined in terms of delay (e.g. information delay), throughput, loss (% of lost information), availability and ICT-security (Yilin et al., 2012). The wired and wireless communication technologies have different QoS capabilities and this may impact consumers' technology choice (Yilin et al., 2012). Service quality affects the later stages of the smart grid adoption process due to the challenges of outage management after new equipment installation. According to Eze et al. (2012), service quality affects the adoption process at the stabilization stage. However, the result shows that service quality affects both framing and stabilization stages due to the challenges of outage management after new equipment installation (Yilin et al., 2012).

The result shows a new factor - process improvement also impacts on the adoption process. This factor refers to the ICT's ability that enhances energy users' business processes and stabilize the adoption (Chinedu Eze et al., 2014). Process improvement mainly influences the framing stage. In the adoption of smart grid solutions, this factor can be defined as the technological solution possibility (i.e., smart grid solution) to improve industrial consumers' business processes.

10.5 Conclusions

Two cases in this section discuss industry's possible opportunities of participating in demand response. Both cases show that there are important parts to be considered for energy flexibility in industrial operations to be implemented, these being regulation and policies, the energy price, smart grid solutions, and branding.

Regulation and policies are vital since they create the incentives to take part in energy flexibility. They can be used as motivation, as it will be easier for industries to fulfill the regulations set by the government.

The energy price is an important factor in energy flexibility for industries. The electricity price may vary greatly in the future, which makes it crucial for companies to have access to the Nord Pool spot price. This will create a greater incentive to provide energy flexibility, as production can be load shifted to hours where electricity prices are lower. The two cases of industries possibly participating in energy flexibility also found that industries do not proactively seek involvement in smart grid activities, but the possibility of utilizing it would create value for the companies.

Another important part to consider is branding. The possibility for the industry to brand itself as a “green company” is found to be important, as this will increase liability towards customers. All industries considered in the two cases either already brands themselves of being environmentally friendly, or sees a possibility of utilizing it, thereby increasing the incentives of providing energy flexibility. Creating an energy flexible service in industries could have a huge impact on the electricity grid. However, to do so, profitability and production rate have to be maintained.

11. Recommendations

11.1 Business ideas for speeding up the market for energy flexible buildings

11.1.1 Introduction

If a market for energy flexibility is going to be developed, it is obvious that emerging business models need to incorporate demand side management (DSM) activities. DSM activities are typically classified into “Energy Efficiency (EE)” and “Demand Response (DR)” and DSM business models usually relate to segments of a typical electricity market: system operation, generation, transmission/distribution, energy retailing and load (Behrangrad, 2015). However, when also considering the market development of Energy Flexible Buildings it becomes apparent that also the heat market and the engagement of the building stakeholders and end users will play an important role.

Buildings can have an important role in energy flexibility due to their potential flexible energy consumption and distributed energy resources (Ma et al., 2016). Different types of building (residential, commercial, and industrial) can provide different energy flexibility, not only due to their energy profiles and DR opportunities, but also according to their potential for adopting energy and monitoring technology or HVAC (Heating, ventilation, and air conditioning) service solutions. The latter can be highly influenced by building and asset management strategies, for example timelines foreseen for maintenance or renovation of buildings. In this respect, there currently seems more potential for business opportunities related to commercial and industrial buildings with high energy consumption than, for example, for residential buildings with low energy consumption.

In the following, business development ideas for energy flexible buildings are discussed based on the DR markets for electricity and heating.

11.1.2 Business ideas for energy flexible buildings in the electricity market

For energy flexible buildings to be supported in the electricity market, two main business concepts have been identified that can provide aggregation potential: Demand Response (DR) and Virtual Power Plants (VPPs). Various stakeholders in the electricity market can, or do already, participate in energy aggregation with new roles or new presence. However, many of them are still searching for links with building stakeholders.

Due to the requirement of volume threshold for aggregation markets - for example the minimum bid to provide primary service in Denmark is 1 MW - buildings can be divided into two main categories according to their energy consumptions: small and large energy consumers. Most residential buildings and some commercial buildings are small energy consumers. Comparatively, industrial buildings and some commercial buildings are usually large energy consumers.

IEA EBC Annex 67 proposes four business ideas for buildings to participate in the energy aggregation market (shown in Table 11.1).

Table 11.1 Four Business Ideas of Buildings' Participation in the Aggregation Market.

	Types	Business Ideas	Direct participants	Indirect building participants
Demand Response	Implicit DR (price based)	1 - building owners participate in the implicit DR program via retailers	Retailers	All buildings
	Explicit DR	2 - building owners (small energy consumers) participate in the explicit DR via aggregators	Independent aggregator	Buildings with small energy consumption
		3 - building owners (large energy consumers) directly access the explicit DR program	Buildings with large energy consumption	
Virtual Power Plants	Trading, balancing, network services	4 - building owners access the energy market via VPP aggregators by providing DERs	VPP aggregators	DER owners (buildings which equip the DERs)

Business Idea 1 – building owners or asset managers participate in the implicit DR program via retailers

There are two types of DR programs: explicit and implicit demand response. The two types of DR programs are activated at different times and serve different purposes in the markets. Consumers can participate in both programs. Consumers typically receive a lower bill by participating in a dynamic pricing program (implicit DR), and receive a direct payment for participating in an explicit demand response program (Bertoldi et al., 2016).

All building or asset managers can participate in the implicit DR program. Building managers can receive the DR program package as part of their electricity supply contract with their electricity retailer. Building users can get a lower bill. For instance, the package allows buildings to reduce electricity usage at peak periods or shift their usage to off-peak periods. It is important to note however, that in this business idea there might be a split-incentive problem as the building user is not always the owner or manager of the building.

Retailers can provide different DR program packages due to their customers' own preferences and constraints and improve customers' satisfaction rate. For instance, if the customer is a building manager and owner of the building, customers' satisfaction rate can be increased due to lower bills. Retailers might get new customers by providing an explicit DR package as competitive offers. In most cases building managers will ask for quality assurance of energy flexibility services as they are averse to user complaints.

On the other hand, some retailers already provide consulting services to customers, such as Energy Efficiency consultancy. Retailers usually do not have professional knowledge in the DR domain, and DR service is a new business idea for most retailers. Therefore, retailers usually need to hire experts and staff for DR business.

Business Idea 2 – building owners (especially with small energy consumption) participate in the explicit DR via aggregators

In business idea 2, building owners, especially of buildings with small energy consumption, can get direct payment by participating in explicit DR programs via aggregators.

Aggregators have to maintain good relationships with customers through: 1) an efficient and customer-friendly payment system and control system; 2) training and consulting service, including DR knowledge and market information sharing; 3) customized DR contracts should be based on customers' energy constraints and preferences; 4) installing direct load control systems for customers or providing a discount or free control system, and/or maintenance service to customers; and 5) providing backup for individual loads as part of pooling activities that can increase overall reliability and reduce the risk for individual consumers.

Aggregators generate revenue by providing DR services to the market (e.g. wholesale market, regulating market, and ancillary service). Aggregators might also receive incentives from regulators, TSOs (transmission system operators) and DSOs (distribution system operators), depending on market regulations and structures.

Business Idea 3 – building owners (with large energy consumption) directly access the explicit DR program

Groups of buildings, assets, neighbourhoods (such as campuses), districts and cities with large energy consumption, can be energy flexibility providers who directly participate and compete directly with producers in the DR market (wholesale market, regulating market, or ancillary service).

To participate in wholesale and balancing markets, large energy consumers need to comply with market rules. Meanwhile, to participate in the reserve market as an ancillary service, buildings need to allow TSOs to directly control energy flexibility resources of buildings (e.g. the building energy management systems).

Building stakeholders or organisations set up for this purpose might receive direct payment by providing flexibility via direct participation in explicit DR programs and might get incentives from the regulators, DSOs and TSOs.

Business Idea 4 – building owners access the energy market via VPP aggregators by providing DERs

In this business idea, building owners (which have DERs (distributed energy resources)) are able to get direct payment from VPP aggregators by providing energy flexibility. The volume threshold for power producers may prevent small DER owners (e.g. households with solar panels) to trade their energy individually. VPP aggregators aggregate DERs and flexible loads as a single entity in the wholesale market, which can help DER owners collectively to participate in the market with lower risk.

Buildings can have different types of DERs. Therefore, DER owners can participate in different aggregation markets. For instance, residential buildings usually only have Photovoltaics (PVs). Due to response requirements for different markets (e.g. primary service in Denmark requires a response in 15 seconds with a minimum of 1 MW, the aggregation potential that DER owners can provide mainly depends on the types of DERs.

VPP aggregators can provide customized market access strategies for different types of DER owners. Meanwhile, VPP aggregators should provide accurate forecast information of supply & demand and user-friendly control system, because it influences the DER owners' daily business or energy usage patterns.

The main reason for DER owners to participate in the energy flexibility market is monetary benefits. Therefore, VPP aggregators need to provide an efficient and fair payment system that also affects DER owners' satisfaction and motivation.

New stakeholders

The ideas and discussion noted above are not meant to be exhaustive. As many actors are still exploring business ideas, new ideas may emerge for developing businesses with less usual stakeholders. For example, various opportunities have been detected with regard to battery storage in homes using new or reused batteries for load shifting, using vehicles as VPP or using blockchain based energy exchange between buildings. Also one Dutch company was detected that provides electrical heating by installing computing units in homes, which are normally installed in server centres. To provide energy flexible buildings, one might thus also reflect about the possible future role of stakeholders from other sectors, such as transport and IT.

11.1.3 Business ideas for energy flexible buildings in heating DR market

The majority of DR research in district heating is still at the experiment stage due to regulatory barriers. The installation of smart metering in district heating will encourage the DR development and implementation in district heating. Buildings can provide flexibility to the district heating grid. The following supporting ideas have been developed, to help guide future business development:

Installation of heat storage tanks in buildings or neighborhoods for load shifting

For instance, some Austrian district heating grid supply and utility companies have introduced hot water storage tanks in a few buildings in order to avoid heat shortage (FGW – Fachverband der Gas- und Wärmeversorgungsunternehmungen, 2018). In this case, the heat meters count heat only after the hot water tank, and losses are paid for by the utility company and not the private heat consumer. This is called distributed storage. Recently a Dutch company[5] also started a seasonal heat storage experiment in a neighborhood.

Price or heat supply signal to shift and smooth loads

Flexible consumers can utilize the thermal mass inherent to their building to shift consumption to periods with a higher share of renewable production. A case study (Mlecnik et al., 2018) has similarly indicated that the daily peak consumption in a building may be reduced by using appropriately designed cost or heat supply signals in Model Predictive Control (MPC) schemes to optimize the space heating operation of buildings.

Supply reduction during peak hours

One demand response initiative (Electricity Directive (2009/72/EC)[6] and the Energy Efficiency Directive (2012/27/EU)[7]) were identified to involve consumers accepting a reduced supply during peak hours. In a case study, demand response was found to be among the cheapest of the evaluated approaches to addressing bottlenecks – partly due to the relatively low investment costs associated with establishing demand response. However, the price associated with implementing DR in buildings would depend on the number of consumers that would be required to participate to address the bottleneck.

Better use of distributed energy resources

The generation portfolio that supplies a district heating network with heat can be diverse and include both boiler plants, CHP (combined heat and power) plants, electrical boilers, and heat pumps. On top of these units, district heating is often also produced from renewable production (e.g. solar thermal or geothermal sources). Shifting towards future-oriented renewable energy sources can imply a major renovation of a heat grid – for example towards lower supply temperatures – which gives a window of opportunity to implement smart control systems in heat grids, branches and connected buildings (Mlecnik et al., 2018).

Utilization of surplus heat from industrial processes

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[5] Ecovat, https://www.ecovat.eu/?lang=en

[6] https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32009L0072

[7] https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32012L0027

Many heat grids are supported by waste heat coming from, for example, industrial zones, greenhouses, water treatment plants or incineration facilities. This gives a relatively high potential for industries to participate in the heat flexibility market; For example, a study in Denmark (discussed in chapter 10 – Industrial consumers) shows that brewery in the case study produces heat and steam from a woodchip boiler because they are not able to use the local fossil free district heating network due to a higher temperature need than the district heating can provide. Therefore, there is potential for industries, such as breweries, to supply self-produced heat to the district heating grid because the surplus heat generated in the industrial processes. However, in the case discussed in section 10, breweries were not able to use the heat in other processes due to tax regulations.

Hybrid networks- combining district heating with other energy networks

"System intelligence" in hybrid networks, combining district heating with other energy networks, is considered to be of great importance in a cross-domain view that coordinates and optimizes storage and transport functions as well as intersectoral load shifting. Researchers have suggested that increased interaction between the electricity and district heating sectors could have beneficial synergetic effects (Lund et al., 2012, Lund et al., 2014). One example of these synergies is the ability to mitigate the curtailment of renewable production by using excess electricity to supply district heating systems with heat from largescale heat pumps (Bloess et al., 2018).

DSM services combining EE and DR

Compared to DR services, EE services have already been developed for various types of buildings and assets. Stakeholders who provide EE services can also expand their activities to provide DR services, as the logical selling point for DR services is the same: the energy cost savings. In theory, demand response solutions and energy flexible buildings have a potential to become part of EE services - such as the thermal retrofit of buildings, energy saving performance contracting, selling and leasing of EE devices, CO_2 emission saving services, and so on, but such examples are not yet encountered. Research done in the framework of IEA DSM Task 17 (2016) can provide additional business ideas. For example, in Austria an ICT-provider placed a SIM-card in boilers: in exchange for the demand response service the owner get free call minutes (Stifter, 2016).

11.2 Policy Recommendations

The flexibility resources and potentials are different for different types of buildings and building asset managers have different needs and behaviours compared to building owners, end users, electricity providers and energy production stakeholders. Thus, it is essential to understand stakeholders' needs and behaviour, not only regarding comfort and energy requirements, but also regarding their possible position within business models, to develop feasible market access strategies for different types of actors. Meanwhile, incentive programs, national regulations, local policies, and energy and construction market characteristics are important to the stakeholders' activation for continuing the development of business ideas.

Sticks and carrots could enhance stakeholders' participation. General and specific laws and rules, specific exemptions, covenants and agreements can be deployed to engage building stakeholders to comply with energy stakeholders' demands, or vice versa. These could, for example, include energy balancing targets, minimum renewable energy share standards, and requirements for energy efficiency or the promotion of technical solutions such as building energy management systems. Economic instruments can also be deployed, such as to move stakeholders into action: grants, subsidies, beneficial loans, revolving funds and tax incentives for investments are all possible policy instruments that lead to an improvement in the adoption of energy flexible buildings. Also disincentives might be applied like tariff structures, where higher consumption of energy leads to higher tariffs, a mortgage system or real estate tax system.

In addition, the involvement of governments and regulators in aggregation can provide incentives and increase DR awareness and participation. However, the aggregation market is still immature, and the regulations and policies of aggregation markets vary across countries. For instance, in Europe, the countries Belgium, France, Ireland, and the UK have created the regulative framework to enable both DR and independent aggregators, whereas other European countries have not yet engaged with DR reforms, e.g. Portugal and Spain.

Furthermore, the European Commission recently proposed new laws covering measures relating to energy efficiency, renewables, and also changes to reorganize the electricity market and tackle energy poverty (European Commission, 2018). It is expected that the upcoming Directives will support the implementation of energy flexibility. For example, the implementation of the revised European Performance of Buildings Directive already introduced the needed deployment of "smart grid ready" buildings in the Member states (Janhunen et al., 2019). Therefore, the business models exploiting aggregation potentials for buildings need to be based on emerging international policies, national regulations and visions regarding energy market restructuring.

In general, factors that influence the energy system transition can be divided into five dimensions:

- Climate and environment
- Societal culture
- Technology
- Economy and finance
- Policies and regulations

The roles, motivations, and barriers for different stakeholders in energy flexible buildings have been discussed in the sixteen cases in this report. Based on the sixteen cases, the opportunities and barriers for energy flexible buildings can be divided into five dimensions as shown in Table 11.2.

By systematically studying the motivations and barriers discussed in the previous chapters and sections, suggestions for how to strengthen the motivations and how to eliminate or reduce the barriers have been developed. The recommendations for related stakeholders are presented in Table 11.3. Table 11.3 shows that, although 'consumer driven/centred' has been emphasized in recent years, policy makers are still the lead stakeholders for strengthening opportunities and eliminating barriers in the energy system. To establish and realize the markets for energy flexible buildings, decentralization of the power hierarchy is necessary, especially for international collaboration and trading.

Table 11.2 Business opportunities and barriers for energy flexible buildings

Dimensions	Opportunities	Barriers
Climate and environment	• The use of renewable energy resources in the electricity grid is already high in some countries and will increase in others. • Reduction of CO_2 emissions and exploitation of local energy sources by using renewable energy like biomass and solar thermal energy will be gradually strengthened	• The use of renewable energy resources in buildings is challenged by building characteristics. The use of renewable energy resources in district heating systems is currently low and requires a shift to next generation heating grids • The CO_2 reduction and local energy use strategies are not necessarily deployed in buildings
Societal culture	• Environmental awareness of climate change and access to low-carbon solutions is increasing • Many consumers are ready to adopt the implicit demand response • Green image encourages companies' DR participation • The increase of fluctuating renewable energy resources in the energy system creates the need to balance the system with DR • Renewable energy communities are rapidly emerging • Innovators and intermediaries provide opportunities to shift the market to the development of strategic niches	• Majority of stakeholders are unaware of energy flexibility • Constraints of indoor comfort and working performance • Constraints of daily business and energy usage pattern • Users lack knowledge regarding DR solutions and willingness to DR participation • Concerns regarding the ease of use of the DR solutions • City densification and network expansions in district heating • Many buildings are too old and need to be refurbished; different buildings have different maintenance and renovation needs • Lack of social engagement in neighborhoods and co-creation for innovation • Lack of communication and collaboration among related stakeholders • Only a few demonstrations show viable market perspectives • Building stakeholders can perceive their relative advantage lower compared to energy stakeholders
Technology	• Building automation and distributed energy resources create possibilities for buildings to provide energy flexibility to the grid • Windows of opportunity for realising energy flexible buildings appear when district heating networks are revised or buildings are renovated • Technologies provide better control and better utilization of renewable energy • DR increases the reliability of the grid • Integration of load management provides opportunities for the use of renewable energy	• Building management systems need to be either installed or upgraded to respond to the demand from the grid • The revision of district heating systems and the provision of thermal retrofit requires a high investment • High complexity of orchestrating demand response in district heating; changes are also needed within buildings • Needs for detailed planning of technical changes in buildings, grids and data management strategies • Multiple control options should be included in the development of smart technologies to achieve high user acceptance

	• Optimization technology for production and distribution of district heating • Some industrial processes, larger non-residential buildings and districts show good potential to provide energy flexibility	• The relatively high complexity combined with the uncertain estimates of the impact • Concerns on data privacy or security issues
Economy and finance	• Energy bill reduction • Financial rewards from the energy supplier • Reduce the need for new investments in the grid by load leveling and load shifting • Create business opportunities for new market players (e.g. aggregators) • Governmental incentives • Possible monetary gain for industrial consumers that have installed distributed energy resources • Price for delivered heat at a defined temperature is high. That give opportunities to converting excess low-price electricity into high-temperature stored heat • Reduce cost by reducing the supply temperature in the district heating grid	• Limited monetary benefits for both electricity and heating DR • Slow Return on investment (ROI) (e.g. smart meters and smart appliances) • Insufficient investment support • Expenses associated with establishing or modifying district heating networks are extremely high • The insufficient benefit of providing energy flexibility to the grid • Uncertainties related to technological costs • Unclear incentive mechanisms
Policies and regulations	• EU climate and energy goals • Installation of smart meters and hourly electricity pricing are ready in some countries and progressing in other countries • There are DR markets in some countries	• Needs for market structure redesign for DR opportunities • Lack of policy incentives and instruments • The complexity of energy system regulation hinders the use of energy flexibility of buildings • Fixed energy prices or prices with a very small variation do not create an incentive to change energy usage habits • The requirement for providing energy flexibility to the grid is high and complicated. • Tariffs and taxes associated with power production is a large barrier to energy flexibility • Unclear schemes for buildings to provide energy flexibility: either everyday or emergency flexibility and either as short or permanent terms • Energy flexibility is not a stakeholder’s sustainability goal and energy efficiency is more important than providing flexibility to the grid

Table 11.3 Recommendation for stakeholders of energy flexible buildings

Lead stakeholders	Related stakeholders	Strengthen opportunities	Eliminate barriers	Dimensions
Policy makers	All stakeholders	Implement policies regarding energy transition	Encourage more renewable energy resources, CO_2 reduction and energy efficiency in an integrated energy and building value chain	Climate and environment
Policy makers	• Consumers • Solution providers (technology and consulting providers) • Energy suppliers	• Strengthen regulatory and economic policy instruments; learn from frontrunners • Deploy organisational and communication policy instruments to create energy use awareness and easy access to low-carbon solutions • Strengthen the use of voluntary or mandatory certificates for energy-efficient solutions, nearly-zero energy buildings and 'smart grid ready' buildings	Regularly evaluate policy instruments regarding: • Analysis and service (including training) regarding consumer energy behaviours • (Software support for) forecast and analysis. • Engagement and collaboration among stakeholders • Efficient and easy solutions	Societal culture
Solution providers (technology and consulting providers)	• Policy makers • Consumers • Energy suppliers	• Develop DR strategies and packages of the control system and DER equipment • Deploy and evaluate easy and user-friendly control systems	• Develop and implement DR solutions; assess feasibility to integrate in electricity services • Propose integrated solutions for specific types of stakeholders • Manage cost for system updating and building renovation • Optimize for multi-inputs, controls, and uncertainties • Develop and communicate solutions and strategies for data use taking into account privacy and security	Technology
Policy makers	• Solution providers (technology and consulting providers) • Financial parties	• Identify specific financial incentives (sticks and carrots) • Provide an easy solution for upfront investment (for example loan or mortgage)	• Develop clear monetary benefits and incentives • Encourage incentives from regulators, TSOs/ DSOs • Strengthen ROI perspectives, for example by communicating a clear time path for deployment of energy flexibility	Economy and finance

		• Lower cost of solutions and equipment, for example by standardising and determining larger quantities for application	• Financially support the (collaboration for developing) equipment control system (e.g. loans, renting, innovation funding) during an innovation phase	
Policy makers	• Aggregators • Consumers	• Detail clear climate and energy initiatives and policies into SMART action plans • Implement flexible energy price schemes	• Facilitate market structure change to support active energy consumers and renewable energy communities; communicate clearly for stakeholders to participate in the DR market • Lower requirements and thresholds to allow smaller consumers to participate in the DR market • Restructure tariffs and taxes to increase the financial benefits of DR participation • Support introducing energy flexibility in aggregator goals and building regulations • Support policies for deployment of smart metering, not only in electricity grids, but also in district heating	Policies and regulations

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