2013–18

Aspern Smart City Research
Final Report ASCR 1.0

ASCR
Aspern Smart City Research

44.10 %

Siemens AG Austria

Siemens Austria is one of the country’s leading technology companies; its business activities are concentrated in the fields of electrification, automation and digitalisation. Siemens is one of the world’s largest manufacturers of energy-efficient, resource-conserving technologies, a leading provider of energy transfer solutions and a pioneer of infrastructure, automation and software solutions for industry.

29.95 %

Wien Energie GmbH

Wien Energie supplies electricity, natural gas and heat to more than two million people, around 230,000 commercial and industrial facilities and public buildings, and some 4,500 agricultural enterprises in Vienna and the surrounding region. It generates electricity and heat from waste recycling, cogeneration plants and renewable energies such as wind power, hydropower, solar power and biomass. Wien Energie is committed to decentralised energy generation and energy services.

20 %

Wiener Netze GmbH

Wiener Netze is Austria’s largest combined gas and electricity grid operator. Its pipelines and cables supplies over two million people in Vienna, parts of Lower Austria and Burgenland with electricity, gas, district heating and telecommunications services – 365 days a year, 24 hours a day. To ensure it can maintain the security of its supply in future, Wiener Netze is investing over € 1 billion in an innovative expansion of its network, to be completed in 2020.

4.66 %

Vienna Business Agency

The Vienna Business Agency offers a 360° service for entrepreneurs in Vienna, including subsidies, consultations, workshops and coaching, support in finding commercial and office spaces, and help networking with partners in the technology scene and creative industries. It also aims to improve Vienna’s position in the international business environment, assists international companies settling in Vienna and serves the first point of contact for expats in Vienna.

1.29 %

Wien 3420 Holding GmbH

Wien 3420 was founded to develop the new district of aspern Seestadt in Vienna. Working together with its partners, it is responsible for space utilisation, urban design, supporting local zoning and development of infrastructure.

Context

Aspern Smart City Research (ASCR) develops technological and socio-logical innovations for the energy world of tomorrow. It is focused on the close interactions between people and urban infrastructure in line with an integral system. ASCR thereby makes an important contribution to achieving the objectives of the City of Vienna's Smart City Framework Strategy.

Urbanisation, the finite nature of resources, demographics, climate change – everyone is talking about these keywords. The trends they reference have, for many years, been among the drivers of the need for social and technological innovations. So far, however, the search for simple solutions to these complex challenges has been unsuccessful. Smart – an equally ubiquitous label, the exact meaning of which is the subject of heated global debate. What what does "smart" mean? Intelligent? Networked? Clever? What should the cities of the future look like? What will they need to offer for their residents to consider them liveable and accept them as valuable living spaces?

Our demands for quality of life continue to rise unabated, as do the demands we place on urban infrastructure such as energy supply, transport, health and waste disposal systems. When cities grow, their infrastructure must be adapted accordingly. If cities aspire to be successful in global competition, they must offer attractive business and working conditions. They have to define and achieve targets (e.g. in respect of energy efficiency, CO_2 reduction and a mobility mix). This requires the "city system" – that is to say, political actors, city administration, companies and citizens – to be receptive to both innovative and disruptive ideas. Urban infrastructure is subject to a depreciation horizon of around 30 years; we will fail to achieve the ambitious aims we have set if we keep patching up our infrastructure rather than modernising it.

But to what extent can technologies and networking help us to support urban development? And what are the risks associated with technological progress?

Knowledge creates value, and and innovative companies create high-quality jobs. ASCR directs particular attention to technological solutions without neglecting the social aspects or consequences of implementing such technologies. It endeavours to take an evidence-based, scientific approach to issues, free from ideological inclinations. Social trends are moving towards a participatory culture – nothing will succeed without citizen engagement. If this premise is correct, we must ask ourselves several questions. What do citizens need to know to prevent them from boycotting sensible solutions out of fear? And what must we do, as scientists and technicians, to allay the citizens' fears?

We need to explain our ideas, approaches and models in such a way that society understands what we are working on and what challenges and problems we hope to solve in doing so. Society, on the other hand, must act as a counterbalance – asking questions, sharing anxieties with us and actively participating in the search for solutions. Only then can society help us develop the necessary systems that will permit us to design sound, sustainable urban infrastructures.

The ASCR research and development programme comprises an array of infrastructure, research and development projects that, in light of their cooperative nature, are closely interlinked. In preparing this Final Report, despite the extensive networking of the projects, we have been taken care to ensure that individual chapters are comprehensible in themselves and can be read separately. In keeping with this approach, any repetitions are accordingly necessary and intentional.

Ulli Sima
City Councillor
for the Environment
and Vienna Public
Utilities

Vienna is growing. It will soon have two million inhabitants, so we should already be developing concepts for the energy supply systems of tomorrow. The goal is to achieve greater energy efficiency with lower CO_2 emissions. We need appropriate energy infrastructure to do this, which takes into account decentralised energy generation and storage and focuses on human needs. Our grandchildren will take for granted the fact that buildings heat or cool their interiors depending on the weather, that intelligent power grids communicate with one another and distribute energy between them, and that we control our energy consumption from our smartphones. ASCR's first report contains numerous tangible results that will, ultimately, lead to market-ready products. I am delighted that this research cooperation between Vienna's public utilities companies and Siemens will also be continued in the years ahead.

As a company with operations around the world, Siemens perceives the global challenges posed by climate change as a mandate for action. We are committed to climate targets and support measures that aim to reduce CO_2 emissions, expand the use of renewable energy sources and increase energy efficiency. Buildings will have a pivotal role in the energy system. We want to provide big-data-based solutions for energy-efficient, intelligent buildings and smart grids, and connect these together. The ASCR test beds offer us the opportunity to develop and test these solutions precisely in a real urban environment.

The results of the first five years of research are encouraging: certain functionalities have already taken shape in real products. We are delighted that the cooperation will be continued and that we will be able to intensify the joint research projects with our partners. Looking to the years ahead, we see challenges in integrating of e-mobility in the energy system and developing intelligent infrastructure to move towards "plug & automate" systems – to allow the solutions we develop to be widely applied.

Cedrik Neike
Member of the Managing
Board of Siemens AG

Aspern Smart City Research (ASCR) is a research association that has been implementing one of Europe's most innovative and sustainable energy-efficiency projects since 2013. With our partners, we are researching the complex relationships in the energy system of the future. We are not only optimising components but are also creating economically viable and scalable integrated solutions. The first phase of the project addressed around 70 research questions that have delivered promising indications for the future of urban energy. This was made possible by the close and trusting cooperation with the City of Vienna and the willingness to make significant investments in research and development – an important location factor.

Numerous solutions have been developed for intelligent buildings and power grid infrastructure and 15 prototypes have been implemented. The results of ASCR's first phase of the ASCR include 30 invention disclosures, with patents registered for 11 of these, and three publicly funded projects that received total funding of €11 million. These successes have also garnered international acclaim: ASCR was honoured to receive the Smart City World Award 2016 for its pioneering role in the field of integrated energy research.

Wolfgang Hesoun
Chief Executive Officer
Siemens AG Austria

Robert Grüneis
General Manager of ASCR

Dr Georg Pammer
General Manager of ASCR

Sustainable and secure energy supplies will be at the core of smart cities. Through its research activities, ASCR has shown that it is possible to strike a balance between the generation of renewable energy and its consumption in combination with smart power grids in urban areas. Buildings as the power plants of tomorrow is another focus of our work. We test the intelligent interaction of all technical components and demonstrate how active integration of customers can work in practice. In the first research phase, which we have just completed, we evaluated data and successfully gained initial insights that have already been incorporated in actual projects. In the medium term, this will create new business models, products and services for energy users. It is clear that the results of our research will lead the way towards the urban energy supply systems of tomorrow.

Peter Weinelt
Chief Executive Officer-Deputy of Wiener Stadtwerke GmbH

When we set up Aspern Smart City Research as a cooperative project more than five years ago, we started with a greenfield approach in many respects. The Seestadt project was still very much in its infancy, and a joint venture of this size and with so many partners was a bold, untested concept. A great deal has happened since then. The trust in the vision and realisation has been justified. The "connection to lived experience" we strove for initially has long since become reality at all levels. Customers were and remain at the heart of the project. Together, we are driven to find the best solutions for a sustainable energy future. Although we still have a long way to go, we are much closer than we were. My thanks to the entire project team.

Michael Strebl
General Manager of Wien Energie GmbH

Our shared mission is to achieve massive reductions in CO_2 emissions. The metropolitan area of Vienna will play a decisive role in this mission. At Wien Energie, ASCR gives us the opportunity to conduct research into topics of the future, such as decentralised energy generation, renewable energies and innovative, digital services, and to test them under real-life conditions in cooperation with the residents of Seestadt. These topics will become crucial for us in the years to come. So, we are delighted that this research will be continued with ASCR 2.0.

Thomas Maderbacher
General Manager of Wiener Netze GmbH

Wiener Netze is a facilitator of the energy transition and a proponent of pioneering technologies in the energy sector. For an innovative company like Wiener Netze, contributing to research is self-evident and indispensable for preserving the quality of one of Europe's best and most secure energy grids. Wiener Netze is proud to collaborate on one of the largest smart city research projects within the framework of the ASCR. The insights gained from this work will allow us to usher in a new age of energy together.

Prof. Armin Schnettler
Senior Vice President of Siemens AG

Around the world, population growth and, therefore, a large proportion of energy consumption, is in cities. In the first five years, the intensive dialogue with key stakeholders in the Seestadt project has proven its worth. The task now is to promote the digitalisation of the energy transition, in particular "behind the meter". We will continue to pilot many of our innovations in Vienna, including blockchain, connectivity and cloud integration applications. We look forward to our continuing cooperation.

Gerhard Hirczi
Managing Director of the Vienna Business Agency

The City of Vienna is making targeted investments in research and technology projects – including in the fields of energy, environment and digitalisation. This is because innovations are essential to securing Vienna's position as a high-performance business centre. The more intensively business and research cooperate, the greater the potential of surviving international competition. ASCR is a shining example of this. I am proud that this research cooperation has found a home in our Technology Center in Seestadt.

Dr Gerhard Schuster
CEO of Wien 3420 aspern Development AG

Seestadt is a place that is open to new ideas and offers perfect conditions for developing technologies for the future. We are, therefore, delighted that ASCR is running its test beds in Seestadt and are happy to support them as they cooperate with building contractors. How buildings can become autonomous energy producers and how residents can shape the future of energy as smart users are intriguing questions for us as a new district in Vienna.

Initial situation and history

The idea of founding a joint research company, led by City of Vienna with Siemens as the exclusive technology partner, was conceived in 2011. The ambitious visions and lofty aims of the participating companies combined with the European Strategic Energy Technology Plan (SET Plan) provided fertile ground for this unique cooperation to flourish. On 5 October 2013, after two years of preparation, ASCR began one of the most innovative and sustainable energy efficiency demonstration projects in Europe. Urban areas and the manifold challenges they face are the core of ASCR's work.

Urban energy efficiency

01 **Initial situation**

A city needs energy. However, despite the fact the general standards for the basic supply of energy do, in all likelihood, exist, each city requires individual solutions. Solutions that work in Vienna will not necessarily work in London, Berlin or New York. But before we implement a solution, how can we know which one to select, where to apply it and why? Where and how can we develop and trial various approaches in a targeted manner?

Political leaders and the administration of a city should be able to make decisions on a sound, factual basis. New technologies and in particular the collection and evaluation of large volumes of data enable us to determine these facts. Handling this data in a responsible manner is a basic principle of any type of research, and ASCR is no different.

In artificial laboratory settings, efforts to develop complex systems that reach out beyond their own domains soon come to the limits of the test environment. As the complexity of a project increases, so too does the need to test prototypical developments in real-life environments in order to be able to remedy teething problems as early as possible, thereby also reducing the costs involved. It is self-evident that technology developers and users are in the same boat or, to put it another way, they share the same interests.

Research and development in the European context

The main objective of the European Union's Strategic Energy Technology Plan (SET Plan) is to develop low-carbon technologies and improve their competitiveness. This makes the SET Plan an important strategic instrument in European energy technology policy.

The European Council's 20–20–20 targets for 2020: In 2007, the European Union set ambitious targets for its energy and climate policy. These "20–20–20 targets" require the EU members states by 2020 to achieve a 20 % reduction in greenhouse gas emissions compared to 1990 levels, to strive to increase energy efficiency by around 20 % and to have 20 % of total energy consumption covered by renewable energies.

The EU's proposed targets for 2030: In 2014, the EU Commission put forward its proposal for energy and climate targets for 2030. This included an EU-wide 40 % reduction in CO_2 emissions by 2030 compared with levels in 1990. At the same time, the proportion of consumption covered by renewable energy should increase to 30 %, while energy efficiency should also increase by 30 %.

Targets for 2050 proposed by EU heads of state and government: Back in 2009, the EU member states unanimously agreed on an EU target to reduce greenhouse gas emissions in the EU by 80–95 % in comparison to 1990 levels. The basis for this target was the so-called two-degree target, i.e. to limit global warming to 2 degrees Celsius.

02 **A joint research company**

In early 2011, a small group of innovative minds gathered in a meeting room at the Vienna Business Agency to discuss an idea that would soon have wide-ranging consequences.

All of the meeting's participants were intimately familiar with the issues on the table. To provide a few representative examples, these issues included:

- How can we successfully establish renewable, CO_2-free energy sources on a major scale in urban areas? What storage systems would be suitable for coupling volatile energy production as closely as possible to consumer behaviour?
- What capabilities must municipal power grids have in future to manage large-scale photovoltaic (PV) plants, decentralised storage systems and e-mobility?
- How can buildings of whatever kind of use be operated cost-efficiently and/or energy-efficiently in future, and what will the effects be when buildings trade on (future local) markets to exploit their flexibilities (such as self-generated energy surpluses, storage capacities and switchable loads)?
- And, last but not least: Are there system solutions on the horizon that could have a radical impact on established companies and their business models?

This small group – composed of representatives from Wiener Stadtwerke, Wiener Netze, Wien 3420 aspern Development AG and Siemens' Research department – soon came to the conclusion that working together on these issues would offer benefits for all involved, provided that all parties involved adhered to certain key framework conditions, namely:

- Exclusivity would have to be established throughout the value-creation chain – new ideas are best discussed when there are no (gross) conflicts of interests and direct competitors are not sitting at the same table.
- A real-life test environment would have to be found – as large as possible in order to ensure national visibility, and as new as possible (greenfield site) to ensure that the participants can help shape the necessary infrastructure as early as the planning phase.
- Sufficient financing would have to be provided from the outset and secured over a suitable period of time in order for the project to provide all partners with a solid basis for their work.
- Regulatory framework conditions and issues of procurement law should be taken into account from the beginning.

The actual idea – that is, the establishment of a joint research company and its underlying corporate purpose – can be summarised on a single side of paper:

- Establish a real test environment in Seestadt (buildings with different uses, a low-voltage distribution grid and a data centre) to allow participants to work with real data;
- Prepare and implement a research and development programme based on the questions mentioned;
- Develop concepts and approaches to solving problems and implement prototypes in the form of a demonstration project.

Thus, the initiative's name practically wrote itself:
ASPERN SMART CITY RESEARCH.

03 **History**

Even back in 2010 and 2011, the City of Vienna and Siemens AG Austria were collaborating in the context of several smart city projects at European and national level. The highest goal was always to develop strategies for integrating climate-related aspects in urban design processes and ensuring systematic implementation of innovative approaches and technologies in the city. The exchange of knowledge and experience played a significant role.

One example of a successful cooperation at national level was the "Smart City Wien" project, which involved sketching out a Vision 2050, a Roadmap 2020 & Beyond, and an Action Plan 2012–2015 for Vienna. At EU level, the future ASCR partners contributed to the "Transform" project – together with representatives from Amsterdam, Copenhagen, Genoa, Hamburg and Lyon – with the aim of developing a transformational agenda for cities to achieve the climate and energy targets of the EU.

Wolfgang Hesoun, General Director of Siemens AG Austria, and Renate Brauner, President of the Vienna Business Agency, signed a memorandum of understanding that ultimately started an exploratory project entitled "Start-up Forschungsgesellschaft Smart City" on 26 June 2012. The project had the following aims:

- Establishing a research company (or a similar form of organisation) with the objective of conducting research and development focused on innovative urban technologies;
- Establishing and operating the necessary infrastructure;

Siemens	Wien Energie and Wiener Netze	City of Vienna (Business Agency, Wien 3420)
• Establish a globally visible showcase • Define the requirements of cities, urban facilities and municipal utilities in relation to the company's portfolio (components, systems, solutions, services) • Assess the results of technology assessments • Develop management concepts and business models	• Develop expertise in the planning, implementation and operation of comprehensive solutions for smart cities • Evaluate real data on investment and operating costs • Determine user needs • Determine requirements concerning modern infrastructure and services • Assess results of technology assessments • Develop management concepts and business models	• Activate financing partners in the field of technical infrastructure • Make real estate more attractive • Construct demonstration buildings and reference projects (implicit)

- Securing full funding of the project;
- Clarifying all details relating to the establishment of the company.

ASCR was founded on 1 July 2013 and, on 5 October 2013, the new company commenced business operations.

04 **The shareholders' expectations at the time of ASCR's founding**

The exploratory project included a survey of the prospective shareholders and identification of their expectations. The "participation economy" is an underlying premise at the centre of ASCR's business activities; it promotes cooperation to develop economic advantages together in cross-company and transdisciplinary teams and continuously strengthens mutual understanding and trust (win-win). In addition, there is broad understanding of the fact that the complexity of many current challenges can only be overcome by combining forces, especially because daily operations and the main factors in cost-effective implementation (such as feasibility, time pressure, cost pressure and lack of resources) are in a permanent state of tension with each other. The original agreement to insulate the ASCR team as much as possible against external (political) influence now appears all the more important to guaranteeing open-mined research and development.

05 **Legal form of the company and shareholders' participation**

After weighing all the criteria identified in the exploratory project, it was decided that a "Ges.m.b.H. & Co. KG" (a limited partnership [KG] in which the general partner is a limited liability company [Ges.m.b.H.]) was the best choice to cover the regulatory requirements under corporation law, procurement law and tax law.

The names of the companies set up for the project are therefore Aspern Smart City Research GmbH and Aspern Smart City Research GmbH & Co KG.

The research company's financing was underpinned by a jointly drafted and agreed five-year business plan. The budget was €38.5 million. It was agreed that no assets in kind would be brought in and that all shareholders would make the required capital available gradually and as required in accordance with their respective holdings (see table below).

Siemens	Wien Energie	Wiener Netze	Vienna Business Agency	Wien 3420 Holding
44.10 %	29.95 %	20 %	4.66 %	1.29 %

06 **Starting signal and schedule**

The research company started operations on 5 October 2013. The smart building, smart grid and smart ICT test beds were implemented and the R&D programme realised according to a rough schedule that gave the ASCR team sufficient scope to make adjustments wherever necessary.

Preparatory phase (2013–2015)

This phase primarily involved planning, setting up and commissioning the technical infrastructure, i.e. the test beds. The smart building test bed and construction sites D5B (student dormitory), D12 (residential building) and D18A (school campus) tired up many of the ASCR team's resources. The close cooperation with planners and building contractors was a new experience for all involved; while this process was not always without friction, it ultimately came to a successful conclusion for all parties.

Research phase 1 – Baseline (2013–2016)

In parallel to construction of the infrastructure, detailed planning was done for the R&D projects (use cases) and work to develop them began. Intensive data collection also started in October 2015, when the buildings were commissioned and tenants moved in. The ASCR team was confronted with the monumental challenges of an integration project on this scale. It took a full year to complete the commissioning of the infrastructure, i.e. to the point where the implemented systems reliably supplied data with the required quality from all the test beds.

Research phase 2 – Control (2015–2018 et seq.)

Following a designated baseline phase, in which all systems were operated in standard mode to provide a reliable initial data base of data, in the winter of 2015/16 the ASCR team began installing all the newly developed, prototypical solutions (building and grid management systems and higher-level control systems). This period therefore involved the bulk of both the research and development work and the field testing. According to the agreement to extend ASCR cooperation until 2023, this work will now be continued.

Final phase – Preparation of the results (2018)

In the first phase, 15 prototypes (primarily software applications) and numerous concepts and models were developed, described in detail and documented in over 300 deliverables.

This Final Report represents the first compact summary of the first phase of the research and development cooperation (2013–2018). The seven storylines in this report (page 48 et seq.) present the key aspects of the scientific results.

The ASCR method

Aspern Smart City Research is a cooperative initiative that aims to find answers to important questions of energy policy with scientific precision, a factual basis and an open, unbiased approach. In keeping with this approach, we carefully select and implement required technologies and, with with the ASCR partners, research and develop them in a cooperative and transdisciplinary approach. In this context, ASCR sees its role as the “enabler”. It offers its shareholders a competition-free cooperation platform with the opportunity to work together on areas of research where they find common interests.

Personnel planning and team composition

Smart cooperation on an equal footing

The core team (from left):
Nicole Kreuzer, Elisabeth Widdeck, Robert Hammerling, Gerhild Kircher, Martin Svaricek, Georg Pammer, Robert Grüneis, Ines Weigl, Roman Tobler, Oliver Juli, Melisa Kis-Juhasz and Andreas Schuster

ASCR does not have a workforce of its own. Everyone working on cooperative research is seconded to ASCR by their company (Siemens, Wiener Stadtwerke, Wien Energie or Wiener Netze) through personnel sharing agreements for varying amounts of time. This strategy, which was defined when the ASCR was established, requires ASCR staff to demonstrate a certain dexterity: when implementing projects, they function on the one hand as employers (as ASCR commissions its shareholders with research and development tasks) and, on the other hand, they serve as a link between the teams of the participating companies. To a high degree, therefore, ASCR staff have a leading and coordinating role. Despite the relative small size of the core team, it has so far experienced many arrivals and departures. Only a few of those present at the outset still remain. See the table on this and the previous page.

Active staff (in alphabetical order)

Name	Seconded from	ASCR role	Since
Beer, Martin	Wiener Netze	Legal Affairs	03/2018
Grüneis Robert	Wiener Stadtwerke	Management	03/2017
Hammerling, Robert	Wien Energie	Infrastructure & Building Operations	02/2014
Juli, Oliver	Siemens	Head of Programme Office	10/2013
Kircher, Gerhild	Siemens	Business Administration	10/2013
Kis-Juhasz, Melisa	Wien Energie	Programme Office	01/2014
Kreuzer, Nicole	Wien Energie	Marketing and Communications	04/2017
Moser, Michaela	Siemens	Assistance	06/2018
Pammer, Georg	Siemens	Management	03/2015
Schuster, Andreas	Siemens	Head of Technical Coordination	03/2014
Svaricek, Martin	Wien Energie	Infrastructure & Building Operations	10/2015
Theil, Andreas	Wiener Netze	Smart Grid/Grid Innovation	07/2017
Tobler, Roman	Wiener Netze	Authorised Officer, Infrastructure	07/2017
Weigl, Ines	Wien Energie	Technical Coordination	04/2017
Widdeck, Elisabeth	Siemens	Business Administration	07/2014
Zoll, Roland	Wiener Netze	Smart Grid/Energy Storage	07/2017

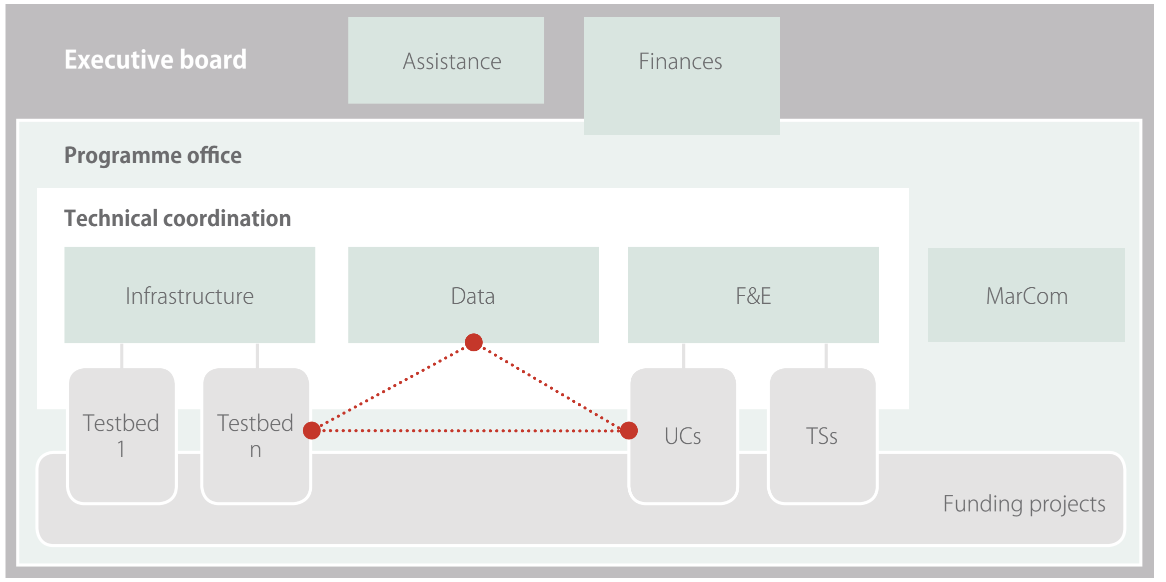
Former ASCR staff

Name	Seconded from	ASCR role	Service
Brehmer, Reinhard	Wiener Netze	Management	10/2013–05/2017
Gerstbauer Christoph	Wien Energie	Infrastructure & Building Operations	10/2019–09/2015
Gressel, Matthias	Wiener Netze	Legal	06/2014–06/2017
Honsig-Erlenburg, Rainer	Wiener Netze	Legal	07/2017–03/2018
Jung, Annemarie	Wiener Netze	Smart Grid	03/2018–05/2018
Kunit, Gerhard	Wiener Netze	Administration/Accounting	07/2017–03/2018
Murauer, Gerald	Siemens	Management	10/2013–11/2014
Pichler, Mike	Siemens	Research	05/2014–05/2015
Richter, Bernd	Wien Energie	Authorised Officer, Infrastructure	10/2013–03/2017
Solitander, Victoria	Wiener Netze	Funding	09/2014–06/2017
Sturm, Monika	Siemens	Head of Research & Development	10/2013–04/2014
Wagner, Nicole	Wiener Netze	Legal	10/2013–05/2014
Wais, Wolfgang	Wiener Netze	Research	10/2013–06/2017

The art of cross-company cooperation
The fact that collaborative endeavours between companies and major national or international funding projects often fail to fully achieve their objectives is due in no small part to major differences in corporate cultures that give rise to clashes.

During peak periods (such as at the height of the Smart Cities Demo Aspern funding project), ASCR's compact core team coordinated just under 200 employees from participating partners. In theory, this arrangement facilitates the most efficient cooperation possible by drawing on the entire pool of specific expertise in the partner companies. In practice, however, the required change in thinking results in hurdles that are sometimes almost impossible to overcome.

In day-to-day cooperation, it is important that all colleagues perceive themselves as equals. Siemens must not simply be seen as a supplier; Wien Energie and Wiener Netze are more than just customers. Overcoming these assigned roles often proves challenging for the team. We are repeatedly forced to question our habitual procedures, company-specific processes and personal thought patterns and break out of them, so that we can effectively exploit the full potential of this cooperation. When this is successful, a wide-ranging base of knowledge base can be developed, with a very good overview of the interests and processes of the participating partners. Development cycles for portfolios, products and services can be accelerated and roll-outs implemented earlier.



ASCR'S CURRENT ORGANISATIONAL STRUCTURE REFLECTS THE COMPLEXITY OF THE COOPERATION

Over the years, the idea of using ASCR as a "tool" for shaping and even securing their own future has taken root. The intensive and ultimately successful process of setting up the ASCR 2.0 research and development programme (2019–2023) is proof that the path forged to date can take the aims of all partners into consideration.

Structure

ASCR has a flat organisational structure, not least due to its size. ASCR has two General Managers: one appointed from Siemens and one from Wiener Stadtwerke. They work closely with the Partners' Meeting, which is held three times per year and is chaired by the Managing Director of the Vienna Business Agency, to ensure that decisions are always taken in the interest of all active operational units.

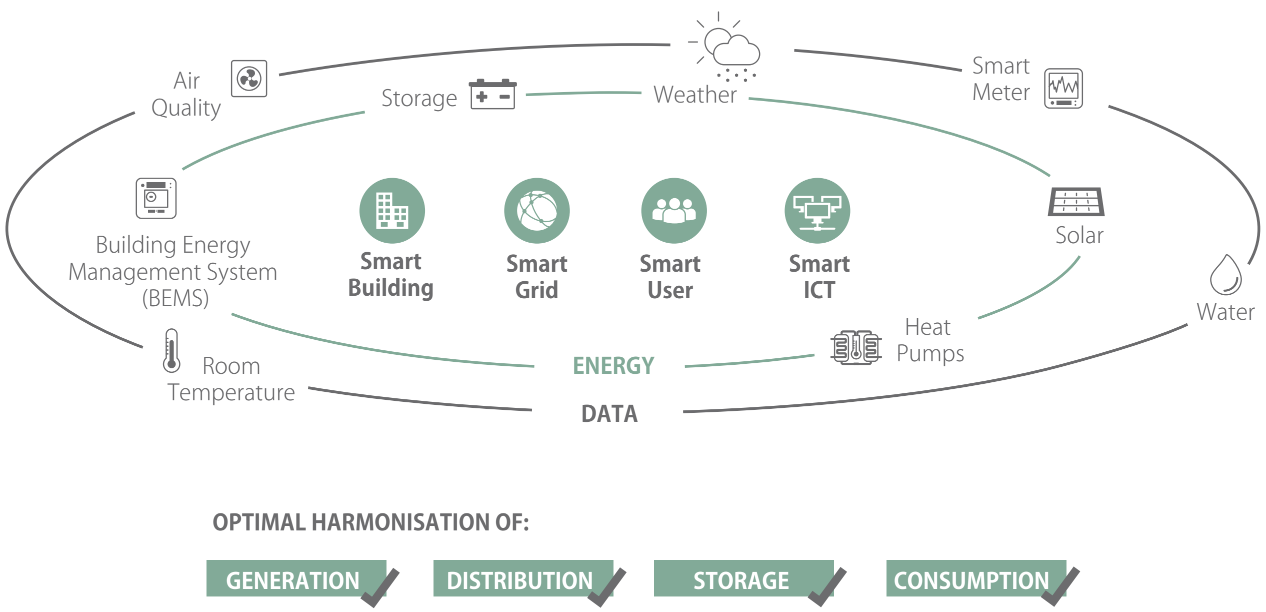
The ASCR 1.0 research and development programme has been implemented and the embedded projects coordinated in close cooperation between the areas of research and development (technologies, use cases), infrastructure (planning, construction and operation of infrastructure) and funding projects.

As ASCR's complexity increased, its organisational structure has needed to be adjusted to new requirements, especially in the final year of the first phase. The Technical Coordination team, which is responsible for the technical implementation of projects in the fields of infrastructure (test beds), data (collection, management) and research (technologies, use cases), is at the centre of this structure. The Programme Office oversees administrative procedures in close cooperation with Financial Controlling.

Location

The ASCR offices are located in the Seestadt Technology Center, in the south-eastern part of Seestadt in Donaustadt, Vienna's 22nd district. The proximity to essential infrastructure for the research work (buildings, grid facilities) facilitated optimal communication with numerous external project partners (e.g. building contractors and planners for the buildings involved) and offered a constant, up-to-date overview of activities on the construction sites. In addition, the impressive views over the ever-growing area of the city provided lasting memories for visitors to the ASCR offices and helped to give our team a sense of "I was part of the team".

The research and development programme or: "the art of asking the right questions"



An overview of ASCR's research areas and most important components

Basis for decision-making
To ensure future-oriented, sustainable energy supplies with a high degree of reliability, performing product tests in labs and trialling new business models through public surveys no longer suffice. Implementing prototypes in real-life environments has long since become an indispensable element in the development of market-ready products and services. ASCR's R&D programme is focused on delivering tangible, usable output. As the participating companies are (jointly) responsible for the programme's make-up, they will – in an ideal scenario – be able to incorporate the results of ASCR research directly in their product and service portfolios.

The fact that the ASCR R&D programme is implemented by a separate research and development company offers numerous opportunities that would be difficult to realise in other arrangements, in particular within the framework established by public procurement law and regulatory requirements. Conversely, the results of our extensive analyses and tests may prove beneficial to the preparation of future legal provisions because they can be based on reliable data. From a research perspective, the ASCR's objectives can be summarised as follows:

- Safe supply of sustainable energy in urban areas
- Provision of a reliable basis for urban design relating to resources (energy, mobility, infrastructure, buildings), quality of life (social inclusion, participation, health, environment) and innovation (education, business, research, technology)
- Automated and intelligent building optimisation systems that can interact with users and external partners (e.g. energy market, grid operators)
- Effective solutions for low-voltage grids relating to grid monitoring and alarm handling, adaptive grid management solutions as well as operational and strategic grid planning tools
- Cross-domain data integration solutions using business intelligence and data discovery methods

Organisation of the research and development programme
Phase 1 (2013 to 2018) of the ASCR R&D programme was divided into four research areas (domains) whose interaction was strongly integrated (see illustration, left).

The four areas of smart building, smart grid, smart user and smart ICT are connected with one another by different energy and data components. Examples of these links include heat pumps and solar energy systems, energy storage systems and building optimisation systems, smart meters, home-automation systems and weather data (see illustration, left).

Eleven specific use cases were carefully defined to facilitate the implementation of the overall ASCR R&D programme; the final versions were decided in the 3rd ASCR Partners' Meeting.

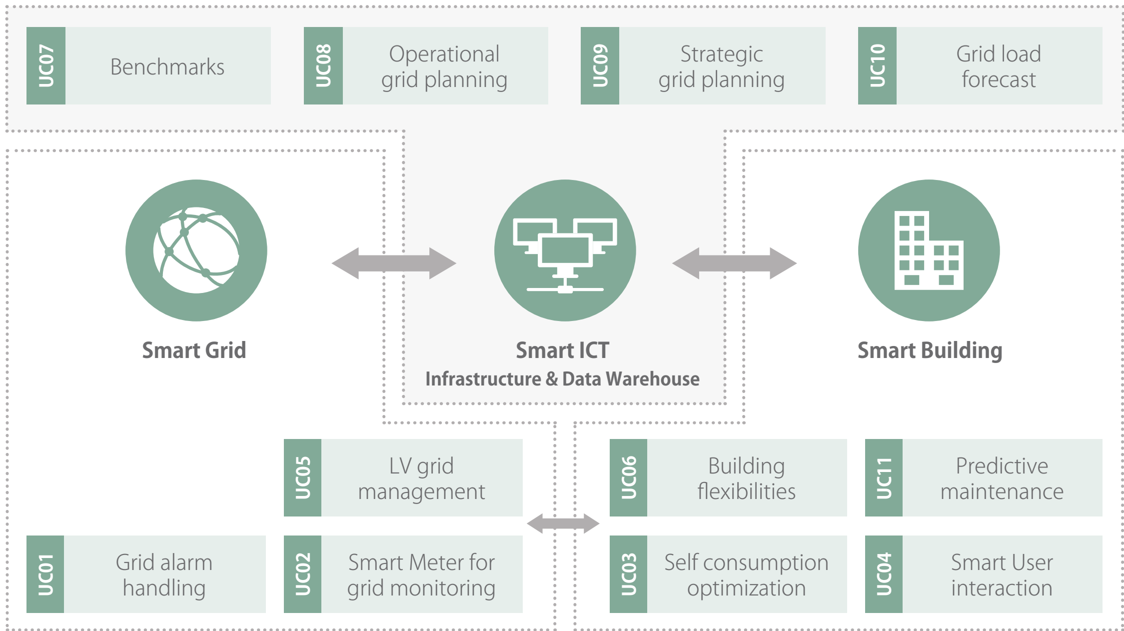
Detailed research questions were defined for each use case. They thereby formed the final link in the chain for the preparatory stage – the core of the research programme.

Brief overview of the use cases and their aims

Use case 1: "Grid alarm handling"
This use case focused on providing operating data from the distribution grid to generate the most precise grid map to support grid planning and monitoring of critical operating states via narrow-band, economical communication media.
The aim is to facilitate optimal use of the available grid infrastructure and to support cost-optimised operating processes to reduce grid operation costs.

Use case 2: "Smart meters for grid monitoring"
Load profiles and other available measurements for commercially available modern smart meters were used as a data source to build a statistical database for long-term grid planning and to determine critical grid operating states and how to handle them in the future. The results will reduce grid operation and expansion costs.

Use case 3: "Self-consumption optimisation"
In this use case, the aim is to minimise energy costs for building operators. This can be achieved by optimising consumption and/or generating extra income through flexibility. At the same time, CO_2 emissions are reduced by integrating renewable energy sources. Optimisations must take into



OVERVIEW OF THE COMPLETED USE CASES

account the comfort of the building's residents or users. It must be possible to implement the measures without negatively affecting comfort. The optimisation process must be automated to ensure efficient operation. Nevertheless, authorised persons must always be able to intervene in these processes and make individual adjustments.

Use case 4: "Smart user interaction"

The aim of this use case is to offer end customers targeted product solutions. Ideally, these should increase comfort for the customer and reduce costs as well as producing markedly lower CO_2 emissions on the energy side. This use case examines social aspects (by researching lifestyles to derive "energy consumer types"), technical infrastructure (by researching required technologies and solutions, including consideration of the existing legal regime) and product range (by investigating product solutions that respond to individual requirements).

Use case 5: "LV grid management"

This use case concerns the integration of decentralised control systems (voltage and/or current) for individual low-voltage sub-grids in efficient grid operation to reduce grid operation costs. The focus is on using solutions that have already been tested in other projects, but with specific modifications, to facilitate efficient operation of the overall system. The focuses include automatic registration of the required components, automatic parametrisation of these components wherever possible, and efficient integration into error management systems.

Use case 6: "Building flexibilities"

The aim of this use case is to market flexibility as profitably as possible. This is an aim pursued by both building operators and energy pool managers. Investments in the requisite infrastructure (building management technology, energy generation, energy storage systems, etc.) must be amortised by the revenues from commercial exploitation. Thermal storage systems can also be used in addition to electrical storage systems. From the perspective of grid operators, these systems can enable them to avoid or postpone the costs of grid expansion.

Use case 7: "Benchmarks"

This use case concerns comparative analysis (benchmarking) in which examining cost-effectiveness is a priority and a comparison is performed in respect of investment costs and the realisable cost savings. In addition to the economic analysis, other performance characteristics (e.g. CO_2 emissions) are also collected and compared. Another aim is to conduct comparisons at different levels of granularity, such as at the level of building equipment elements, complete buildings and pools of buildings.

Use case 8: "Operational grid planning"

This use case involves supporting decision-making in operational grid planning to reduce the costs of grid operation by the cross-domain and decentralised integration of data from different sources and common data models. The aim is to ensure easy and efficient access to data by providing data from sensors in the field. This use case also examines the structure of interfaces and interactions between domains.

Use case 9: "Strategic grid planning"

This case is focused on developing simulation environments that make it possible to estimate the potential impact of strategic grid expansion measures, taking into account external factors, to reduce grid connection costs. Through model-based optimisation with validation and complex data analysis, the aim is to identify nexuses and generate new information from the data. Furthermore, it aims to provide support in setting up an app or API platform.

Use case 10: "Grid load forecast"

The aim of this use case is to improve the quality of (generation and consumption) forecasting at connection points to the grid through automated day-ahead forecasting and intra-day forecasting on the basis of self-learning algorithms to reduce balancing costs. It involves the ongoing recording of (bidirectional) transformer station data and weather data (via sensors at transformer stations) and setting up a historical database. In addition, where known, calendar events (such as major public events) are also recorded. In addition, forecasts are generated using intelligent algorithms that process current and historical data for each transformer station and subsequently summarize data for each connection point at the respective transformer stations.

Use case 11: "Predictive maintenance"

The aim of this case study is to perform periodic maintenance work now and thereby reduce maintenance costs as necessary. It also hopes to improve the focus on customers by preventing or resolving faults before customers notice their effects.

Processing the results

The results of ASCR's R&D programme are made available to all partners in the form of "deliverables". Both brief answers and more detailed responses to the research questions have been prepared in the documentation for each of the use cases. The demonstrations (applications, services, tools) comprise 15 actual implementation examples (prototypes and adapted products) that operate in real-life conditions in the test beds.

Thanks to national funding projects (the SCDA, iNIS and FACDS projects were awarded almost €5.8 million in funding – see the "Funding" section), most of the use cases were able to expand their scope to examine issues more extensively and in greater detail than originally planned (additionality).

The most significant research results have been summarised in the form of storylines to provide an overview in this Final Report.

Connections to the Smart City Wien Framework Strategy

The Smart City Wien Framework Strategy includes both quantitative and qualitative targets for 2030 and 2050 and is thus an authoritative guide for strategic and sustainable policy action. The applicability of individual aspects of the overall project for neighbourhood monitoring systems was analysed, in particular in the context of the SCDA project. These insights could provide valuable input for urban design and district management.

The foundation of research – test beds

Constructing the test beds in aspern Seestadt (January 2014)

The complex and interconnected test beds form the basis for the ASCR's research and development activities. The focus in planning and implementing the test beds was on creating the most comprehensive, sustainable infrastructure possible – for instance, to reduce primary energy demands from the outset. This makes it possible to save several tonnes of CO_2 emissions every year – very much in line with the City of Vienna's smart city goals.

The individual infrastructural components and systems of the smart building and smart grid test beds as well as adequate ICT architecture (Smart ICT) were selected with an eye to the R&D programme and combined to form integrated solutions. Creating complete solutions makes it possible to gain a holistic view of the correlations and interactions between the domains.

Motivation and aims

In the course of conception and planning, considerable attention was paid to ensuring that the prospective test beds offered the greatest possible flexibility. Consequently, constructing building and grid infrastructure that corresponded to real-life needs was not the primary aim. The test beds were intentionally fitted out with the widest possible array of technologies to facilitate the processing of as many complex issues as possible in a real-life environment.

For instance, different types of sensors, heat pumps and transformers were selected in order to compare their performance and characteristics.

Due to their hidden inherent complexity, it is not possible to resolve urban issues on the basis of "armchair" decision-making: the risk that external factors might be overlooked is too great. Complex challenges of this kind must also be examined in reality; the suitability of solutions must be trialled if they are to prove effective when put into practice later on. The ASCR test beds offer the perfect "playground" in which approaches developed in theoretical terms can be tested in reality before being rolled out across the entire supply area.

One example is the development of smart grid applications, which would be markedly more high-risk without an appropriate test bed. An ever-applicable piece of developers' wisdom rings true in this regard: the earlier you can identify a fault, the cheaper it is to eliminate. For instance, replacing faulty software that as been rolled out in hundreds of transformer stations is markedly more costly than conducting a well thought-out practical trial.

Description of the test beds

In all, the process of planning, constructing and commissioning the ASCR tests took around three years (2013–2015). The ASCR team, working in collaboration with all partners, implemented the test beds successfully in both technical and economical terms and therefore created an asset that can be used sustainably.

ASCR is the owner of the test beds and is responsible for operational management of all facilities. This ensures that the test beds are equally available to all shareholders and can be used efficiently for the benefit of all partners. By providing a work platform, ASCR takes on the role of a coordinating "enabler". At the same time, this role should ensure that all actors (industry, energy suppliers and grid operators) are clustered effectively and can develop orderly responses to the questions in the R&D programme.

ASCR's framework also provides a project management environment that compels results-oriented cooperation. The research components mean that innovative approaches are continuously introduced and discussed and that any "organisational blindness" can be overcome. If nothing else, the required focus on results ensures that comprehensive documentation is produced for all projects.

The ASCR test beds will continue to be used in the ASCR 2.0 research and development programme, and will be further expanded according to new requirements.

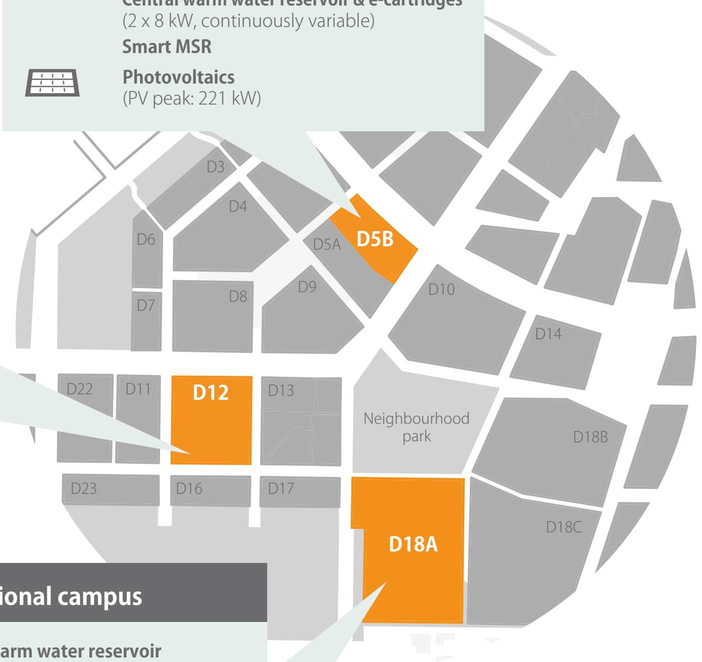
Smart building

Buildings account for around 40 % of total end energy consumption throughout Europe. One main focus of ASCR is, therefore, optimising the private consumption of energy in buildings. Future building optimisation systems will be configured to forecast likely energy requirements, taking into account usage habits, energy saving behaviour, energy production, weather forecasts and other data. In addition, they will be able to provide information regarding the status of specific building units and assist in planning maintenance measures.

Three building complexes – one residential building, one student dormitory and a school campus (comprising a nursery and a primary school) – make up the ASCR's smart building test bed. These different building types were selected to make it possible to observe their different uses and requirements. Unfortunately, at the start of the ASCR cooperation, no office buildings that could have been integrated in the test bed were available.

These three buildings, which are fitted with photovoltaic, solar-thermal and hybrid systems, plus heat pumps, different thermal and electrical storage systems and state-of-the-art IT, act as flexible "prosumers". This means that, as well as consuming energy, they also produce and store their own energy. Complex ICT systems facilitate the automated and optimally controlled distribution, use, storage and transmission of energy. Smart buildings are also able to participate in the electricity market.

SMART BUILDING TEST BED IN THE SOUTH-WEST OF SEESTADT



D5B Student hall of residence

Electricity storage system (150 kWh available)
Central warm water reservoir & e-cartridges (2 x 8 kW, continuously variable)
Smart MSR

Photovoltaics (PV peak: 221 kW)

D12 Residential buildings

High-temperature water reservoir (6 x 2000 l)
Thermal underground storage tank (approx. 6,000 m³ or 40,000 kWh)
Electricity storage system (2 kWh)
Home automation (111 households)
Smart MSR

Solar thermal energy (90kW)
Photovoltaics (PV peak: 15 kW)
Hybrid (peak: 20 kW electrical + 60 kW thermal)

Various heat pumps (approx. 700 kW thermal)

D18A Educational campus

Central warm water reservoir & e-cartridges (70 kW, step-wise variable)
Smart MSR

Solar thermal energy (90 kW)
Photovoltaics (PV peak: 58 kW)

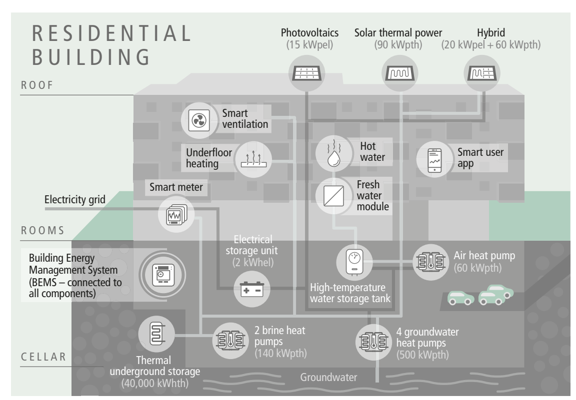
2 heat pumps (510 kW thermal)

D12 – Residential building

The housing complex comprises six individual elements with a total of 213 subsidised apartments on a total surface area of approximately 16,000 square metres. The ground floor features commercial spaces and a two-storey underground collective garage. The building is completely self-sufficient in heating, i.e. its built-in systems fully cover its heating requirements. The building generates energy with its solar-thermal, photovoltaic and hybrid systems (the last being a mix of photovoltaic and solar-thermal systems) as well as through heat pumps. These renewable sources deliver a 71 % reduction in annual CO_2 emissions when compared to a gas-fired heating system. This corresponds to a saving of approximately 240 tonnes of CO_2.

ASCR also uses the waste heat from the garage with an air source heat pump. Due to the constant ambient temperature, the efficiency factor was successfully doubled in winter. In addition, a novel concept for an underground thermal storage system was also successfully put into operation in this building.

The 111 participating households (see storyline 1) were fitted with smart measurement and control technology. This allows users to control the air quality and temperature of their home using smart home automation, both from the apartment itself and remotely via their tablet or smartphone.



RESIDENTIAL BUILDING ON PLOT D12 INCL. TEST BED FEATURES

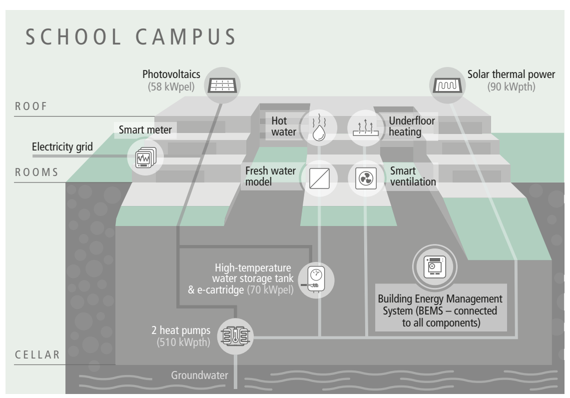
VIEWS OF THE RESIDENTIAL BUILDING ON PLOT D12

VIEWS OF THE SCHOOL CAMPUS ON PLOT D18A

VIEWS OF THE STUDENT DORMITORY ON PLOT D5B

D18A – School campus

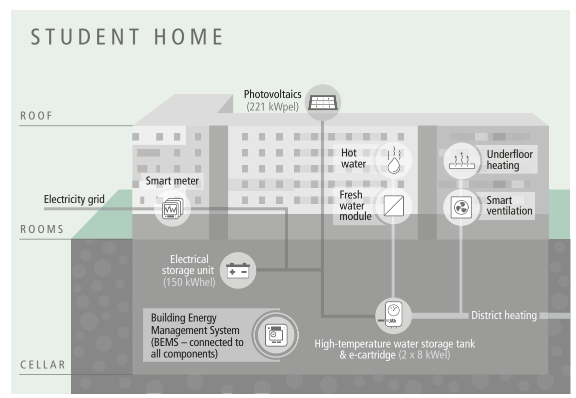
Thanks to the technical infrastructure of ASCR, the school campus is self-sufficient in heating. At the time of writing, the campus accommodates 233 children in the nursery and 420 primary school pupils. Energy is generated by solar-thermal systems, PV systems and heat pumps. One special feature of this building is that heat is extracted from the waste air heated by the body temperature of the building's users and heat is also produced by its technical equipment when in operation. This energy recovery measure makes it possible to save € 10,000 per year on energy costs. The aim is to use practical demonstrations such as this as proof that integrating innovative energy concepts in modern urban construction is both technically and economically feasible.



SCHOOL CAMPUS ON PLOT D18A INCL. TEST BED FEATURES

D5B – Student dormitory

The "GreenHouse" student dormitory provides accommodation for 313 students on 7,000 square metres. The building was constructed in compliance with the Passive House Standard. The Austrian Sustainable Building Council (ÖGNB) honoured the "GreenHouse" for its sustainability in February 2014. The building's electricity is generated by photovoltaic systems installed on the roof. By implementing a battery storage system, ASCR raised the level of self-use of this energy to 62 %, increasing the share of the building's energy requirements covered to 48%. The total surface area of all the PV panels on the student dormitory is greater than that of the roof itself (diversified, layered coverage). While this means that not every panel is optimally positioned, it does maximise the potential total energy yield. Heat and hot water are supplied through district heating.



STUDENT DORMITORY ON PLOT D5B INCL. TEST BED FEATURES

Outlook

In the infrastructure (i.e. in the test beds), ASCR is working on innovative energy concepts and focuses on sustainability. The operation of the various decentralised systems is optimised to supply heating, cooling and power in the best possible manner. The research conducted at ASCR therefore not only has a societal impact but also allows the ASCR partners to shape the energy world of the future by becoming "first movers".

During the first phase of ASCR cooperation (2013–2018), all test beds were set-up and fitted with extensive sensor and measurement technology and management functionalities. In the second phase (2019–2023), the ASCR cooperation partners will continue to use the existing infrastructure and expand it according to the requirements of the new research topics. Potential areas of expansion include both the existing premises and entirely new buildings and building complexes (one office building is in place so far).

The following technological expansions are under discussion for implementation in phase 2:

Electrical storage systems

Expanding these systems from individual buildings to an entire neighbourhood, thus connecting the infrastructure of several buildings, is not only a sensible move in terms of optimising the system: shared use of storage systems in a neighbourhood is economical, ecologically beneficial and has economic value.

Neighbourhood storage systems can be implemented to feed into the grid (grid-friendly) and/or to serve the market (market-friendly). Whether configured to be grid-friendly or market-friendly, there are various operational strategies that can, to some extent, be combined to produce multi-use strategies. Multiple users will increase battery utilisation and thus also commercial profitability. It should be assumed that, in addition to large-scale storage solutions, flexibilities will also increase in the lower power range (photovoltaics, home storage systems, e-mobility, etc.). At the same time, energy markets are becoming more volatile. We will develop solutions and products to make profitable use of markets in the course of our future research.

Thermal storage systems

District heating systems are particularly popular in industrial conurbations. Renewable energies are set to play an increasingly important role in district heating in future. One method of achieving this is to recover heat from wastewater. It is advantageous that that sewerage and district heat networks are similarly widely connected throughout the city. Furthermore, there is a certain degree of simultaneity in the generation of wastewater and the demand for hot water; this aspect can also be exploited.

Chemical storage systems

Storage technologies and sector coupling (such as the synergy of electricity and heat supply systems) will play an increasingly important role in future. As electricity production from renewable sources will fluctuate according due to weather conditions, technologies need to be found that will ensure the required energy is available in the form needed. So, hydrogen storage systems and corresponding applications must be a key research topic for ASCR in future.

Cooling

The topic of cooling in the residential sector has so far been broadly underestimated. As our summers become increasingly hot and a new record for the number of tropical nights above 20°C is set almost every year, a change in thinking is essential. Just like the cold in winter, high temperatures are not only unpleasant but also have enormous effects on the human body. At the test bed residential building (plot D12) in Seestadt, which was not fitted with cooling systems, many residents have decided to install split-system cooling units. These are not ecologically friendly and are inefficient. An anergy network can provide comfortable cooling simply, efficiently and sustainable. Loosely speaking, an anergy network is a local heat supply system. However, it is operated at a temperature that differs only slightly from the ambient temperature. An anergy network can therefore be operated using the waste heat from operational systems, such as a computing centre. In a smaller residential area, an anergy network offers certain advantages when compared to a district heating network. In the ASCR's second phase, our research will examine the technical and economic feasibility of anergy networks. If the results are positive, we will implement such a network.

Some renovations would be required to provide sustainable cooling in the existing test-bed building, such as delivering cooling via the flooring or through the air intake. Outside the heating period, the energy required to produce hot water should be drawn primarily from the existing floor heating system using cold water and heat exchangers. This should cool or adjust the rooms to an acceptable temperature.

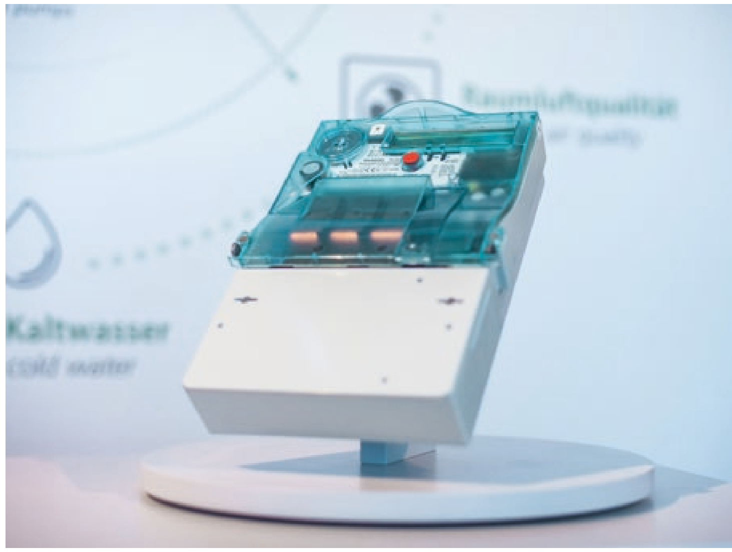
Use of groundwater

Two buildings in the ASCR test bed are self-sufficient in heating (the residential building and the school campus). This means that they are not connected to the district heating grid and instead generate all the thermal energy they require on their own with the help of renewable energy sources. A large proportion of this energy is generated by groundwater heat pumps. Removing thermal energy from a body of groundwater inevitably cools this water. Some buildings in Seestadt, resort to the use of groundwater. In the next phase of the project, the reciprocal influences of these neighbouring groundwater wells will be observed over the long term in order to improve existing simulations.

Smart grid

The ASCR's smart grid test bed is composed of two sections in the distribution grid. The main part is located in Seestadt. Beyond that, however, some transformer stations with different characteristics (rural, urban and industrial consumers) from the Wiener Netze supply area have also been connected to obtain more meaningful results that better reflect real-life conditions.

At the low-voltage level, the central test bed in Seestadt is composed of 12 transformer stations, 24 loop cabinets and 5 storage systems that serve the grid. These core electrotechnical facilities are supplemented with around 100 grid monitoring devices (GMDs) that provide high-resolution data on the grid and make this visible in detail. There are also 500 smart meters; more than 100 consumers have given their consent for processing the averaged 15-minute data from these meters. The consumption figures for the remaining households are available for processing as an aggregated group.



ABOVE: A SMART METER. BELOW: A GMD (GRID MONITORING DEVICE)

The extensive installation of sensors and actuators in the low-voltage distribution grid is new, as this voltage level – unlike the high-voltage level – has not been monitored or manually operated to date.

A key aim of ASCR's work in relation to the power grid is to determine the number of sensors and actuators required for grid planning and operation in future, to find the optimal cost-benefit balance between efficient expansion of the sensors and visualising the grid by collecting measurements.

The environment provided by ASCR in Seestadt is particularly well suited to researching such issues. Indeed, declarations of consent for wide-ranging data applications were obtained before the research began, while many tenants and building contractors in the research area demonstrated a basic willingness to cooperate. This made it possible to secure a datapool that was a crucial basis for researching the questions.

By adopting a holistic approach to planning processes and them deploying of primary technology (energy supply) and secondary technology (sensors and telecontrol technology) in an integrative way, a symbiotic environment has been created in the ASCR research area. This makes it possible to develop responses to the future-focused issues faced by a distribution grid operator in the topic areas of the smart grid, grid planning and asset optimisation at the low-voltage level.

In addition, the test bed as established can also be used to develop solutions not only for existing but also for planned regulatory measures and to ensure that they are ready for implementation by subjecting them to adequate testing. Regulatory provisions aimed at achieving qualitative improvements in power supplies, such as the determination of quality performance indicators, are particularly relevant. These parameters, which are evidence of the quality of a grid operator's service, are primarily based on indicators from the low-voltage level, such as those collected in the ASCR test bed. Solutions of this type can have a direct impact on the economic performance of a grid operator because supply quality is a significant factor in the grid charges set by the regulator.

OVERVIEW OF THE SMART GRID TEST BED AND THE SMART ICT TEST BED (DATA CENTRE)

Outlook

In ASCR 2.0, the research project will examine in further detail other factors which directly impact grid operators as well as regulatory framework conditions. The focus will be on grid-friendly energy storage systems, applying flexible grid tariffs and facilitating the data exchange required for efficient grid operation. For this reason, the fact-based, technical test bed has been supplemented with a legal-regulatory test bed in which the effects of legal provisions on the energy market and the efficiency of the distribution grid operator can be examined. This innovation will support the design of legal requirements adopted by the government. In this way, the grid operator gains an information advantage that can be used to the benefit of customers in this rapidly growing part of the city.

As the technical composition of the ASCR test bed provides a real-life setting, future observations in this field will be able to investigate the synergies between a large variety of equipment operated by a modern distribution grid operator. This includes, in particular, the potential for synergies between smart metering and operational measurements to facilitate data-supported grid planning and operation. The aim of these observations will be to identify the optimal mix between required stanard equipment such as smart meters, other technically necessary measurements, and to supplement these with mathematical methods.

The extensive use of field sensors and actuators will present an as-yet unquantifiable challenge to distribution grid operators in terms of the data networks that will need to be created. There is accumulated demand for knowledge and practical experience in both logical and physical information security, specifically from the predominantly manual management of the low-voltage distribution grid described above.

Efficient development of the required measures means that new technical concepts not only need to be drawn up but also tested in practice. The aim of a dual approach such as this is to create a feedback control system between the development of theoretical concepts and their practical testing with the aim of constantly making the overall system more resistant to cyberattacks – which also continue to evolve.

The aforementioned technological shift that grid operators will be unable to avoid in the framework conditions outlined above, means that automation components can only be rolled out in the field in large numbers efficiently and effectively if a standardised framework is established. The current state of the ASCR environment means it will be possible to develop and test a corresponding, future-proof standard composed of procedures and the technologies used.

Smart ICT (data centre, communication technology, field system)

Applying intelligent information and communications technology (smart ICT) makes it possible to use the data from buildings and the low-voltage distribution grid, as well as external data, to analyse the complex interactions between the buildings and the grid. Using data from different domains enables a holistic, comparative analysis to be prepared for an urban area. This can then be used, for example, to map out new nexuses in complex urban systems or to investigate the effectiveness of optimisation measures.

The three main components of the ICT system architecture are the data sources, the Teradata database (data warehouse (DWH)) and the users. The database server used is the Teradata 670C model.

In contrast to the usual "data silos", which implement separate, independent database solutions for each individual business area, ASCR's smart ICT facilitates a holistic representation. Consequently, there is no need to use different tools to load or visualise the various datasets.
The most serious argument, however, against the use of these "data silos" is the fact that, due to the fragmentation of data, it is not possible to obtain a consistent, global view of the data pool – something that is utterly essential for all cross-domain analyses based on this data.

The ICT test bed was therefore constructed to have complete integration of all heterogeneous data by use of a company-wide logical data model. Specifically, the data from the smart grid and smart building domains and from external data sources are integrated in the ASCR data warehouse to provide a combined view of the database for all cross-domain analyses. The smart grid logical data model (SG-LDM) is the basis and central element for this extensive data integration: it is a logical, relational data model that depicts all of the different objects from the different domains (e.g. measurement equipment, building sensors, etc.) and their interrelations in a complex entity-relationship diagram (ER diagram). The heterogeneous and distributed data is combined to create a common, consistent database through this SG-LDM – and its specific implementation as a physical data model in the DWH. The SG-LDM is composed of two elements:

- the Teradata utilities (logical) data model (UDM), which comprehensively covers all business segments and domains in the energy sector, and
- the smart grid enhancements of the UDM, which are specifically designed to meet individual requirements derived from the use cases.

The core of the SG-LDM is the Teradata UDM, a very comprehensive and complex corporate reference data model. The scope and complexity of the UDM is depicted particularly clearly by the model's ER diagram.

In light of this complexity, the most sensible approach appeared to be to use an existing data model as the foundation and expand it individually, rather than designing an extensive new data model from scratch. This approach was realised and implemented using the SG-LDM.

ASCR's existing ICT ecosystem is used to test which databases can be provided in an urban environment and in what form, to enable them to be used by either municipal authorities or provided to local residents for their own applications.

The use of the ASCR test bed makes it possible to develop a comprehensive knowledge base in a short time. What is more, in the area of ICT field security in particular, targeted testing activities – which would not be possible to the same degree in an area with fully fledged production operations – can improve the overall level of information security. The experiences gained through the use of the ASCR test bed have already contributed significantly to the fulfilment of regulatory requirements (e.g. the Austrian Cybersecurity Act and the GDPR).

Outlook

The expected high density of sensors and actuators produces a continuously growing pool of data by itself which, to remain manageable and usable in an effective manner, must be kept to an adequate minimum level. In addition, questions concerning the type of data processing (such as centralised/decentralised, different data science methods), operating costs and their information content must be addressed. In doing so, the existing, growing data pool and the cadre of interdisciplinary experts form crucial fertile ground for solutions so that "a blessing does not become a bother", as Goethe once wrote.

The digitalisation of the (low-voltage) grid enables grid operators to optimise their grid planning and operation activities while using fewer personnel and material resources. In order to realise efficiency gains from digitalisation to the fullest possible extent, it is important to keep the costs of digitalisation to a minimum. Technologies such as "plug & automate" components, data analytics and automated ICT security must be deployed throughout the entire system. A homogeneous approach should also be adopted across all voltage levels.

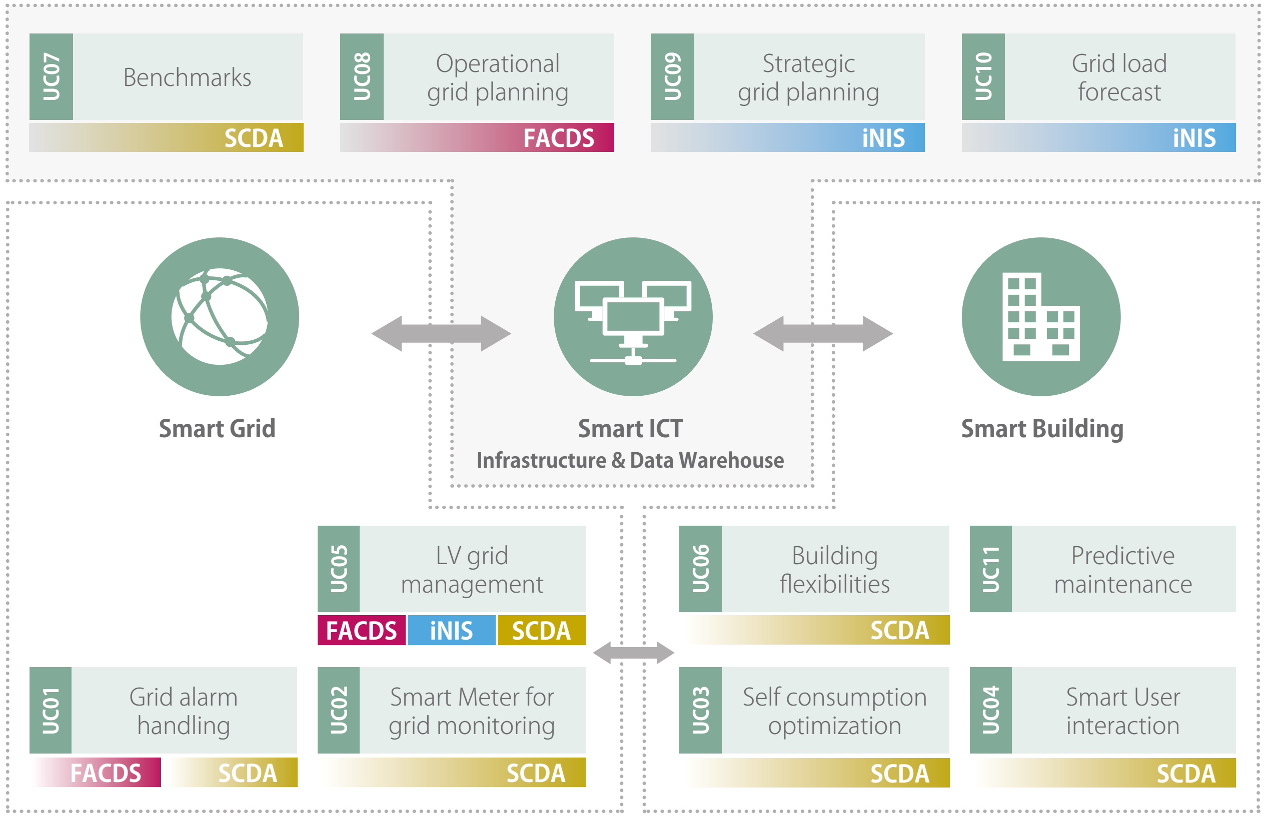
At the same time, digitalisation serves to connect different domains, such as buildings, energy grids and regional energy generators, to achieve overarching objectives such as energy efficiency. Furthermore, digitalisation increases the resilience of the system as a whole through the use of corrective monitoring systems.

For companies participating in the energy market, digitalisation is the basis for creating personalised offers for their customers. Classic companies thus become providers of tailored solutions and remain closely connected to their customers. At present, the grid operators' ICT architecture is characterised by a highly centralised concentration of data-processing systems. Data, such as from sensors in a substation, is recorded and processed centrally in a control system.

This architecture covers the current case in which several decentralised points (i.e. substations) are connected to a central control via broadband. However, this relationship is not capable of supporting a grid distributed over a wide area and connecting data points of differing quality, such as a low-voltage distribution grid with its transformer stations and loop cabinets. For this use case, it must be examined to what extent systems can also process data decentrally, which can be made accessible if necessary.
To this end, ASCR is testing distributed ICT systems that can be equipped with different applications depending on the specific use case. The aim is to identify the optimal system architecture depending on the different environmental parameters.

The technology selected for the data centre (primarily Teradata as the central data warehouse) is very well suited to storing and reading data in a structured manner (relational database management system (RDBMS)). However, due to the relatively low volumes of data, low numbers of parallel users and the fact it is not in productive use, the main advantages of the RDBMS (scalability, simultaneity, consistency) are only available to a limited extent. So-called "duality" will therefore be important for the future: a classic, relational system of this type for the "productive world", combined with a highly flexible system that can serve research and development even better. In future, this will result in a shift away from a "one-technology-fits-all" strategy towards a multi-technology platform approach. This trend, which can be seen and is being implemented around the world, further heightens the importance of issues such as data governance and data security.

Targeted funding support research



Allocation of funding projects to ASCR use cases and test beds

Funding strategy

In an innovative environment and the relevant discussions, cooperation between companies is essential for successful research and development activities. Cooperation provides insights into neighbouring fields of research and work that would not have been possible if the companies had acted alone. In this way, joint projects and their results can be examined, discussed and interpreted from multiple perspectives.

At ASCR, research is designed to be integrative and transdisciplinary. This approach promises a strong focus on outcomes and, therefore, an increased chance of the results being transferable into practice in the energy sector. Participating in funded research projects supports this approach; the contribution of external partners adds a further dimension. It therefore is an important strategic tool for ASCR.

Funding and subsidies not only help companies and institutions in research and development but also serve to secure locations as centres for business. The Austrian Research Promotion Agency (Österreichische Forschungsförderungsgesellschaft, FFG) pursues two primary goals: First, it acts as a platform for processing funding, such as that awarded by Austrian governmental institutions like the Federal Ministry for Transport, Innovation and Technology (BMVIT) or the Climate and Energy Fund (KLI.EN); second, it acts as a broker in national and international programmes supported by funding providers, including the BMVIT and KLI.EN and the European Union.

However, many results from research funding projects indicate that, despite identifying impressive solutions, commercial implementation them remains difficult. There is still a gap between the innovative idea and its application or transfer to real life. Not least because of this, ASCR is focused on implementing solutions in practical terms in test beds.

To fully implement the ASCR research and development programme, it was necessary to take the following steps:

- Detailing of the R&D programme by means of use cases
- Grouping of use cases and project definitions
- Selection of suitable funding programmes
- Selection of suitable external partners (formation of consortia)

Three project ideas were developed and submitted by different consortia. All three applications were approved by the respective funding providers and provided with almost € 5.8 million towards a total project volume of € 11.4 million:

- Smart Cities Demo Aspern (SCDA) as part of the 4th invitation to tender of the Smart Cities Demo (KLI.EN)
- integrated Network Information Systems (iNIS) as part of the 3rd invitation to tender of ICT of the Future (BMVIT)
- Flexible AC Distribution Systems (FACDS) as part of the Energy Research Programme, 2nd invitation to tender (KLI.EN)

The figure on the left illustrates the allocation of ASCR use cases to this project funding. Each of the implemented projects covers important aspects of a modern smart city concept. This, they implicitly support efforts to achieve the objectives of the Smart City Wien Framework Strategy in the areas of innovation, resources and quality of life.

Smart Cities Demo Aspern (SCDA)

Project summary
The aim of the key SCDA project was the first-ever large-scale implementation of a system-optimising approach in the areas of buildings, power grids, ICT (information and communication technology) and user engagement. The demonstration project was implemented in Seestadt in the form of three networked test beds (buildings, low-voltage distribution grid & data centre). Over the term of the project, we were able to use the insights gained and conclusions made to improve the operation and control strategies of buildings and power grids. Furthermore, the project drove forward the development of different approaches to user interaction to achieve optimised energy use and the resultant reductions in CO_2 emissions.

"Using flexibilities intelligently"

PROGRAMME
Smart Cities Demo, 4th invitation to tender (KLI.EN)
CONSORTIUM LEADERSHIP
Aspern Smart City Research GmbH & Co KG
PROJECT PARTNERS
Siemens AG Austria, Wien Energie GmbH, Wiener Netze GmbH, AIT Austrian Institute of Technology GmbH, PSA Projektleitung Seestadt Aspern, MOOSMOAR Energies OG, TB Käferhaus GmbH, SERA energy & resources e.U., MA18 – Urban Development and Planning
PROJECT VOLUME
€ 7.9 million
TOTAL FUNDING
€ 3.6 million
PROJECT TERM
3.5 years (April 2014–September 2017)

The project objectives were fully achieved. The insights gained in implementation of the project can now be used to adopt improved operating and control strategies for buildings and power grids. This makes it possible to achieve optimal energy use and reduce CO_2 emissions. Consequently, strategies need to be drawn up to translate the solutions developed to entire urban districts. Details and conclusions can be found in the publishable final report.

integrated Network Information System (iNIS)

Project summary
In the iNIS project (2015–2018), existing data sources in the network (counters, sensors) were used to improve operational and planning-related network operation. The analysis of the measurement data collected facilitated

- improved monitoring of grid conditions,
- more precise consumption modelling (load models),
- greater knowledge of the reserves available in the grid,
- and thus more efficient grid operation.

The last point made it necessary for the grid operator to use new data processing methods and technologies of mass data (big data) processing, because their existing ICT systems were not equipped to do so.

"Making grid status visible"

PROGRAMME
ICT of the Future, 3rd invitation to tender (BMVIT)
CONSORTIUM LEADERSHIP
AIT Austrian Institute of Technology GmbH
PROJECT PARTNERS
Aspern Smart City Research GmbH & Co KG, TU Wien – Institute of Energy Systems and Electrical Drives, Salzburg Netz GmbH, Siemens AG Austria, Wiener Netze GmbH, GRINTEC Gesellschaft für grafische Informationstechnologie mbH, Teradata GmbH
PROJECT VOLUME
€ 1.8 million
TOTAL FUNDING
€ 1.1 million
PROJECT TERM
3 years (April 2015–March 2018)

The project can be seen as an important step towards increasing system efficiency.

Flexible AC Distribution Systems (FACDS)

Project summary
The FACDS project (2016–2018) concerns the definition of grid-friendly functionalities of future decentralised storage systems in electrical distribution grids with simulation-based technical validation at the system level and component level. Laboratory validation of safety-related storage aspects of a prototypical system design, the functional validation of system services and their stability, and the design and operation of storage system in the distribution grid with real-life implementation in the ASCR test bed played important roles in the project.
In addition, it conducted legal, technical and economic analyses on the basis of a cost comparison across the entire life cycle and contrasted the specific costs of different storage system deployment strategies. The project also highlighted potential barriers and issues relating to the operation of storage technologies and strategies for their use. The multiple-use aspect was also taken into account. Scenario-based business models can then be developed on this basis.

"Integration of grid storage systems in the power grid"

PROGRAMME
Energy Research, 2nd invitation to tender (KLI.EN)
CONSORTIUM LEADERSHIP
Wiener Netze GmbH
PROJECT PARTNERS
Aspern Smart City Research GmbH & Co KG, Siemens AG Austria, Wien Energie GmbH, AIT Austrian Institute of Technology GmbH, Energy Institute at the Johannes Kepler University Linz, Forschung Burgenland GmbH
PROJECT VOLUME
€ 1.7 million
TOTAL FUNDING
€ 1.1 million
PROJECT TERM
3 years (February 2016–December 2018)

The project had not yet been completed at the time this report was drafted.

1

Living and working in a smart city of the future

We require energy to keep rooms at a comfortable temperature, for information and entertainment, for bright working areas and to keep drinks cool. In truth, we are not usually all that interested in how much energy is consumed but rather in the price of the energy we need and that our needs are reliably met. Our energy consumption (in watt-hours, or Wh for short) and the power we use (in watts, or W for short) are higher or lower depending on how we behave as users and the technologies we use. So, one of ASCR's objectives is to investigate user behaviour in commercial housing, to make its residents more energy-conscious and to test potential instruments to guide user behaviour.

Motivation and objectives

Energy affects every area of life: a reliable supply of energy is the backbone of a functioning and innovative society. Digitalisation enables us to exploit the potential for optimisation of energy efficiency and CO_2 savings and thus helps to enhance the quality of citizens' lives. Everyone aspires to lead a "good life". The Smart City Wien Framework Strategy provides a basic outline of how this can work. It proposes resource efficiency and innovation measures to achieve the best possible quality of life for Viennese residents. The framework strategy therefore also serves as a guide for the ASCR activities.

In the building sector, considerable efforts have been made to reduce energy requirements since the 1990s. The focus is now on the next step: not only should buildings consume less energy, they should also produce energy. In an ideal scenario, buildings should become power plants in which they cover their own energy requirements and generate a surplus – and exploit this commercially, for example as control energy without neglecting the requirements of the underlying power grid (cf. various aspects of storylines 2–7).

The concept of buildings participating in the energy market has been a topic of discussion for some time, and is known as moving "from consumer to prosumer". The user behaviour of a building's occupants is a decisive factor in the levels of energy consumption and the power actually used as well as the construction methods used and the technical equipment and systems installed in a building. The objective of the ASCR's sociological research study was to determine how certain interventions, such as a home automation system, targeted information campaigns or a time-of-use tariff would affect the user behaviour of a building's occupants and, therefore, the building's energy balance.

Integrating smart users

The ASCR's sociological research activities were focused on the residential building on plot D12. On moving into the building in 2015, 111 households consented to the recording of all energy data and room comfort-related parameters at the household level and its subsequent use in scientific evaluations. The home automation system installed in the apartments did not pose any additional costs to the households. The overall system also features an eco-switch that can be used to switch predetermined sockets on and off, a control system for the underfloor heating and a CO_2-based control system for the ventilation system.

In addition, the plan from the outset was to develop and produce a smartphone app in cooperation with the households.

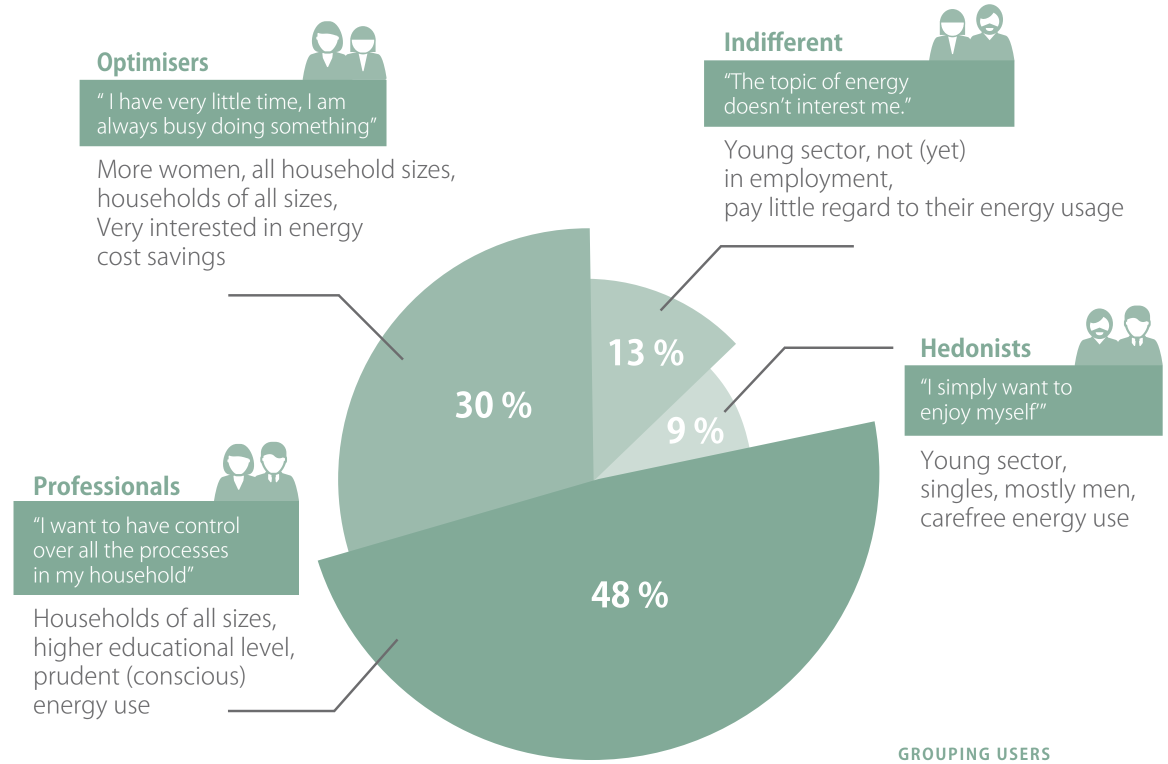
> The objective of European Union's climate and energy policy is to structure the EU's economy and energy system to become more competitive, more secure and more sustainable. Am-ong other aspects, greenhouse gas emissions should be reduced by 40 % by 2030 compared to 1990 levels, while the share of total energy consumption covered by renewable energies should rise by 30 %.

Grouping users

A survey of the participating households was conducted at the start of the sociological investigations. This was carried out, firstly, to find out more about their attitudes, values and behaviour patterns and secondly, to use the insights gained to design project activities and accompanying measures that would have a high degree of acceptance. Then, on the basis of these results, the households were allocated to different user groups.

It became clear that almost half (48 %) of those surveyed were technically proficient and interested in the topic of energy and sustainability. In the context of the project, this group was designated as the "professionals". They are open to technical explanations and specialist discussions, know a lot about energy, understand the energy technology connections and are interested in sustainability.

Almost one-third (30 %) of those surveyed designated as the "optimisers". While these people have little technical or energy-related knowledge, they have a keen interest in reducing energy costs and a certain interest in sustainability. This group



GROUPING USERS

Handling data in a responsible manner

CONTEXT

Wherever data is collected from individuals, and above all where the ASCR requires such data for different applications, handling this data in a responsible manner is a fundamental requirement. ASCR is aware of the major responsibility it has in relation to the processing of personal data and therefore acts in accordance with the principles of legality, transparency, purpose-related appropriation, storage limits and data security. A privacy policy specifically tailored to ASCR's situation informs participants about all aspects of the processing of their personal data (transparency) and makes it easier for them to find information outlining their rights and options in the context of data protection law. This policy comprises the following:

- ASCR processes only personal data that is required for the research activity or for information services and does so only for as long as is necessary for this work or as long as is stipulated by provisions of the law. The processing of personal data is performed in strict compliance with the applicable provisions of data protection legislation. ASCR does not publish participants' data or transfer it to third parties without permission.[1] The data is exclusively processed within the EU. The legal basis for this data processing is the declaration of consent signed by the participating user.

- ASCR only works with processors who can provide sufficient guarantees that suitable technical and organisational measures have been taken to protect personal data and, therefore, that it is ensured that data processing complies with the requirements of the EU General Data ProtectionRegulation (GDPR). Data processors exclusively perform data processing on the basis of a contract that precisely stipulates the duration, type and purpose of the processing. All processors who process personal data are reviewed and monitored on a regular basis to check whether they do indeed comply with the provisions of data protection legislation.

1 Personal data is only transferred or otherwise transmitted to third parties when necessary for the purpose of the research activity and the user in question has given their express consent.

- Our participants' personal data is stored and secured with particular care and attention and using state-of-the-art technology. Their data is protected against accidental or unlawful destruction as well as against loss. For reasons of data security, personal data is pseudonymised and encrypted wherever possible. Technical systems and organisational measures are designed so that the confidentiality, integrity, availability and capacity of the systems and services related to the processing of personal data are permanently ensured and so that the availability of personal data and access to the same can be quickly restored in the event of a physical or technical incident.

- Reviews, assessments and evaluations of the efficacy of the technical and organisational measures are conducted on a regular basis in order to ensure the security and processing of data. All uses of this data, including in particular changes, requests and transmissions, are logged to ensure that the legitimacy of these uses can be demonstrated to the required extent. All data security measures are documented in detail.

- The Chief Information Security Officer (CISO) of ASCR works closely together with management and is the primary point of contact for issues relating to data protection and data security. Technical experts also convene at regular intervals to address issues relating to data security and data protection. The Chief Information Security Officer is responsible for instructing and advising the management and employees who process personal data in respect of their obligations and duties under data protection law as well as for monitoring compliance with these legal regulations. The Chief Information Security Officer works together with the supervisory authority and serves as a contact partner for the supervisory authority on issues relating to the processing of personal data, including prior consultation. Data subjects can consult the Chief Information Security Officer in relation to all issues concerning the processing of their personal data and the assertion of their rights.

- The ASCR also requires all employees who come into contact with personal data in their professional activities to complete internal data protection training at regular intervals. ASCR strives to raise and intensify awareness among all employees regarding respecting and protecting personal data.

- Nevertheless, in the case of a personal data breach, the ASCR shall be obligated to inform the data protection authority of this breach immediately.

would appreciate straightforward instructions or intuitive products that can help them to save on energy costs. This group is not particularly interested in explanations of the connections related to energy use or in receiving detailed information.

Of those surveyed, 13 % were termed “indifferent”: they possess few technical skills and have no significant interest in energy issues or sustainability.

Only 9% of respondents were allocated to a group of people who, though technically proficient, have no interest in energy or sustainability, designated as the “hedonists”.

Three-quarters of participating households took part in the first survey in 2015. In the following years up to 2018, the proportion of households that took part in annual surveys on user experiences and habits in relation to the installed technology remained at around two-thirds.

Are the participating households representative of the wider population?

The survey conducted at the start of the project shows that the majority of participating households could be assigned to the “professionals” group. This can probably be traced back to the fact that, of the 213 households in building D12, those who responded to and participated in the project have a fundamental interest in energy-related topics. In light of this bias, the shares of the “optimisers”, “indifferent” and “hedonists” groups are probably larger in reality than for the households participating in this study. Attitudes towards data privacy likely also contributed a certain degree of bias. The households participating in the project did not state this as a priority. Therefore, we do not argue that the results of the surveys can be generalised. Nevertheless, it has been possible to derive conclusions for application in future projects.

Supporting user behaviour through automation and learning

Even if people take a keen interest in topics relating to energy and sustainability, the demands of daily life often leave little scope for active decisions that are guided by the requirements of measures to reduce CO_2 emissions or boost grid stability and that would lead to changes in user behaviour. For the most part, people’s time is occupied with organising and managing their daily lives. It therefore stands to reason that high importance should be placed on introducing automation-supported mechanisms in conjunction with financial incentives to guide user behaviour. Nevertheless, education and information initiatives are very important: they enable households to make informed decisions and actually take advantage of the financial benefits and automation-based support that such mechanisms offer.

Home automation and smart home control

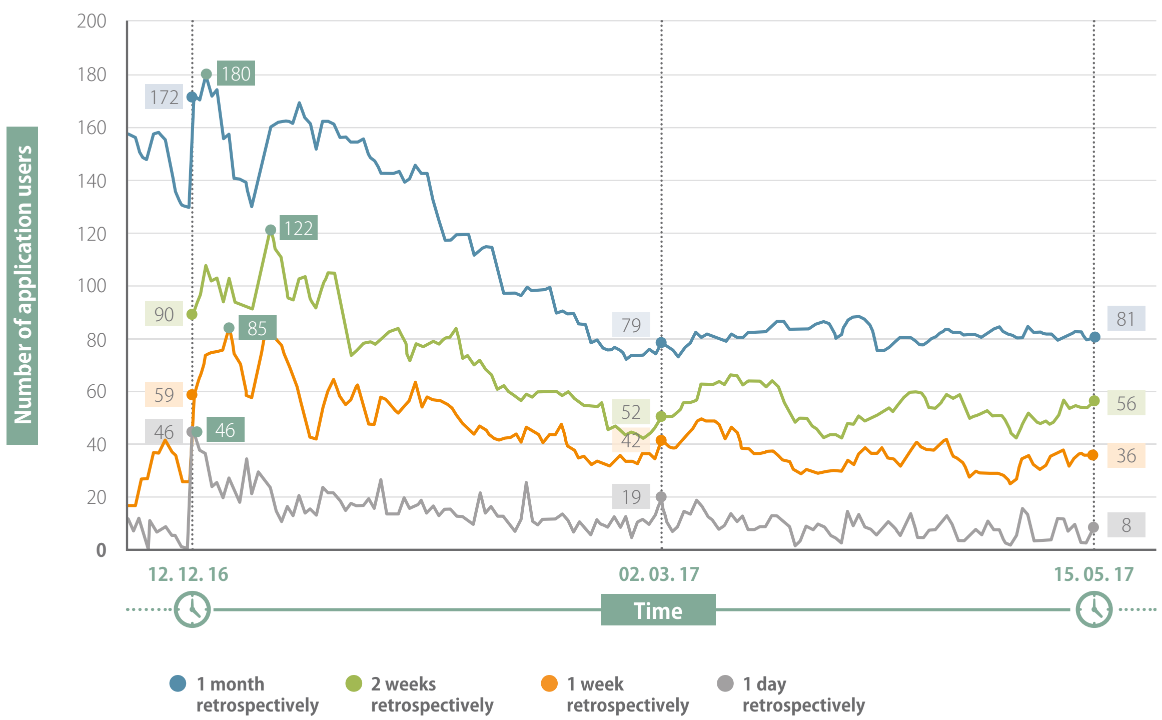
The home automation system installed by the ASCR replaces the manual system previously installed by the building contractor and is supplemented by the smart home control app, the eco-switch and the automatic CO_2-based ventilation control system. In the first year of the study, it became evident that the dissatisfaction with the ventilation system expressed by some of the residents could be traced back to the planning and design work during construction – that is to say, these issues were not caused by the control system installed by ASCR. Further feedback provided highly valuable input for efforts to improve the home automation system.

Smart home control app

The requirements for using a smartphone app were met because, at the start of the project, 90 % of those surveyed said that they used a smartphone. The app’s design and functionalities were developed using feedback from workshops and surveys. The participating households have been able to use the smart home control app for smartphones and tablets since December 2016.

The most common request from the surveyed households was for a cost comparison (for energy and heating) – that is to say, a feature that contrasted their actual costs with those of an average consumer. Features highlighted as important included additional control options for lights and blinds, individually programmable profiles for heating systems, individually controllable ventilation levels, a mould-control function (in which ventilation level

Smart home control app in use



OVERVIEW OF SMART HOME CONTROL APP USE OVER TIME

automatically increases in case of elevated air humidity), information on air quality, individual switches for each individual socket controllable via an app, and a functional control feedback system (i.e. to check whether a given function is working properly, or to provide an error message).

In the app's second stage, all of these functions were realised except for light and blind controls, individual socket switching and input feedback "confirmation".

The app makes power consumption, hot and cold water consumption and heating consumption transparent and makes it possible to configure comfort parameters. A survey on the acceptance of the smart home concept and the smart home control app showed that 80% had a positive opinion of a smart home. More than half of the respondents had a positive impression of the app. Users particularly appreciated the display of and prompt insight into consumption statistics, as well as the consumption comparison that allows them to draw conclusions regarding their own usage behaviour, and the remote access to the thermostat. The app's visuals have also been well received.

More than half of those surveyed use the app at least once every two to three days.
On average, residents use the app for around one hour per week. The analysis of access requests shows that residents use the app intensively when newly downloaded – but that it is used less frequently as time goes on.

The evaluations performed by the ASCR therefore show clear parallels with other national and international research projects on the same topic.

Eco-switch
The eco-switch is connected to plug sockets and can switch all of these sockets on and off at the same time. The evaluation shows that the eco-switch is primarily connected to media (printers, scanners, TVs, radios, CD/DVD players, games consoles, etc.) and certain kitchen devices, e.g. coffee machines. Less than half of those surveyed use the eco-switch when they leave the house for several hours or more. The objective of supporting households in efforts to save energy through the eco-switch was achieved. The evaluation of the data shows a trend towards reduced power consumption through use of the eco-switch.

Changing user behaviour through knowledge and electronic support
The research project shows that user behaviour can be changed through knowledge and electronic support. Alongside the precondition of practical feasibility, the following factors help foster the use of electronic instruments: very simple operability, clear relation between cause and effect, sensible pre-configurations, feedback on target attainment and consideration of learning and familiarisation effects. Information should be simply prepared and easily accessible. Users have learned about energy use through trial and error and through information provided by ASCR. The results of the accompanying research demonstrate that fitting apartments and residential buildings with basic automation components that take the requirements and behaviour patterns of different user groups into account should be expanded to include different real-life situations and to support people in their daily lives. Regular events and other recurring information offerings are sensible methods of helping residents to learn how to handle the new technology and also take into account the turnover of tenants and the familiarisation effect identified in the energy consultancy.

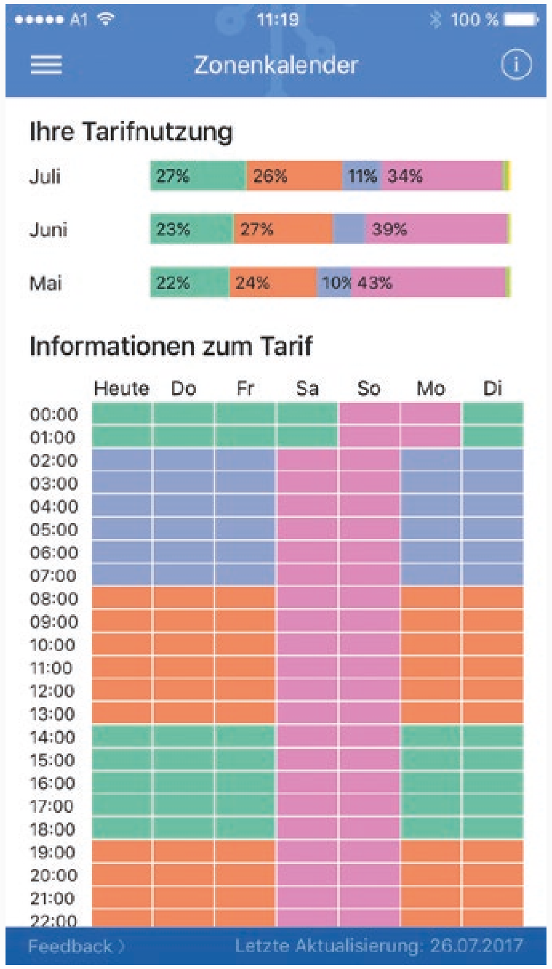
Provision of information and corrective action
The "open day" event format was proposed to the participating households in order to respond to queries about the installed technology. In practice, this format also addressed problems that had nothing to do with the research project. The format therefore proved to be an effective instrument through which to collect and report design defects that tended to increase energy consumption during the subsequent use phase.

Building quality and usage behaviour
The ASCR's research activities also confirmed the influence of actual building quality on energy consumption in the use phase. In terms of execution quality, there were problems with electrical installation in relation to the eco-switch, the ventilation system and the apartments' ability to adapt to summer conditions. In the warm season, the apartments suffered from overheating that led to complaints and, in some cases, to residents purchasing ventilators and cooling devices. In 2018, 53% of the household surveys were equipped with ventilators, while 12% had air-conditioning devices. Methods to guide user behaviour had clearly reached their limit. Changed user behaviour cannot be used to balance shortcomings in building planning or errors in execution. The ventilation system, overheating in the warm season and consequent cooling requirements must initially be solved by improving the building's construction and household technology.

Time-of-use tariff
Between June 2017 and the end of 2018, selected households trialled a time-of-use tariff both with and without critical peak pricing. The app displayed the time zones to participating households and the corresponding energy prices. In addition, one group of households received push notifications from the smart home control app informing them that the energy price would increase or fall significantly in the coming hours (critical peak pricing). It became clear that households with very low consumption levels and a very low tariff already in place were not able to achieve savings through these tariff types. On the other hand – in a less surprising development – households with higher consumption levels were able to achieve half-year savings of up to €100 compared to their previous tariffs.

The evaluations indicate that the trialled tariff models help to shift the time of consumption, but tend not to achieve a genuine reduction in energy consumption. For future research activities, it would be worthwhile considering tariff simulations with higher comparison tariffs, as larger price increases are expected on the energy markets in the coming years.

Resident participation



Summary and outlook

Testing in reality increases resource efficiency
One particular aspect of the accompanying socio-logical research is that the ASCR team does not conduct a pre-selection and works with everyone who agrees to participate in the planned research activity in writing by the deadline.

In the course of the building planning phase, the ASCR team concluded agreements with the project's building contractors concerning the energy supply systems and smart home control systems to be installed, but did not add any additional require-ments for the building's envelope or the execution quality. This ensured that it produced a realistic picture of the issues that would be encountered in widespread application of these technologies. Against this background, the results – which appeared rather sobering at first glance – can be regarded as thoroughly positive.

At the same time, however, it is important to emphasise one point: smart building automation or smart home automation cannot be installed to compensate for previous errors and defects in the planning and/or execution phases. If users are motivated to think and act in the interests of energy efficiency, the quality of the apartment, its devices and control systems must be commensurately high.

Residential buildings as participants in the energy market
Tailored tariff models managed to shift energy demand in the participating households to a small extent. Eco-switches and ventilation systems do not have a major role to play in the energy market. Eco-switches primarily help households to save energy. The ventilation systems, which are con-trolled by room comfort parameters, create addi-tional but – when planned according to energy efficiency criteria and correctly installed – low energy demands and primarily serve to improve the health of residents. Additional power consumption peaks caused by the increasing installation of cooling systems due to overheating from April to September have implications for energy efficiency. Energy companies could potentially develop a business model in response to this by creating water-based cooling systems. Such a system would certainly benefit the residents' comfort.

Guidance from policy instruments
In view of the importance of subsidised housing, further investigations should be conducted to examine the extent to which funding models could be revised, such as increasingly taking actual energy consumption into account. A significant foundation for this was laid for Vienna in 2014 with the Amend-ment to the Austrian Building Code (Bauord-nungsnovelle), which now requires the actual energy consumption of buildings to be reported three years after commissioning (in the notice of completion). Fitting apartments with temperature sensors could be made standard practice, as could requirements for ventilation systems, summer comfort (i.e. ensuring comfortable indoor tempera-tures in the warm season) and basic building automation.

2

Energy-efficient and self-sufficient buildings: Supply concepts based on alternative energy sources

Use cases 3, 4, 6, 7 and 9 as defined by ASCR are aimed at developing, implementing and using a building energy management system (BEMS). Such a system requires the integration of alternative energy sources to optimise the internal consumption of energy in different building types. This is technically feasible and opens up promising avenues for building contractors and operators to use existing flexibility.

Motivation and objectives

Intelligent buildings and components of alternative building technologies (e.g. heat pumps, solar-thermal systems, photovoltaic systems and energy storage systems) have been established in the construction sector for several years. However, such components are usually not well adjusted to each another or to the requirements of building operation (an issue exacerbated by, among other aspects, the individual usage behaviour of users in a building). Often, control strategies are only implemented from a business perspective for the individual components: a holistic, optimal strategy is not considered. This limits realisation of eixsting potential for energy and cost savings. Furthermore, even well-equipped buildings are generally operated without taking external framework conditions into account, including tariff conditions, grid bottlenecks or environmental conditions, which likewise limits the scope for improvements in system and cost efficiency.

To counteract this trend, the ASCR R&D programme aims to derive insights from the optimised interactions of novel building components (primarily alternative energy sources, such as photovoltaic systems combined with heat and electricity storage systems, and components that can be used with flexible schedules, such as heat pumps with suitable measurement and control technology) in real-life field tests. For this purpose, renewable and decentralised supply solutions should, on the one hand, facilitate affordable yet comfortable living conditions through urban development while, on the other hand, and in addition to optimising costs in business terms, also create opportunities for buildings to interact with the distribution grid and with the energy markets.

To achieve this, it was necessary to develop a building energy management system (BEMS) that makes use of flexibilities available in a building (e.g. shifting heat pump heat generation processes to times when locally installed photovoltaic systems generate the most electricity). These flexibilities, which are also realised, for instance, through the use of electrical and thermal storage systems and energy converters (heat pumps, electric heating elements, etc.), are exploited in order to optimise building operation based on different parameters. Thus, the following use cases can be distinguished by:

1. Minimal operating costs: The building optimises electricity purchasing and feed-in to the grid based on 24-hour price forecasts. The present storyline addresses this use case.

2. Optimal energy purchase: Based on a price forecast for the day ahead, the building plans a cost-optimised load profile that shows energy requirements over time. To cover these requirements, it purchases energy on the day-ahead market. This strategy is examined in storyline 5.

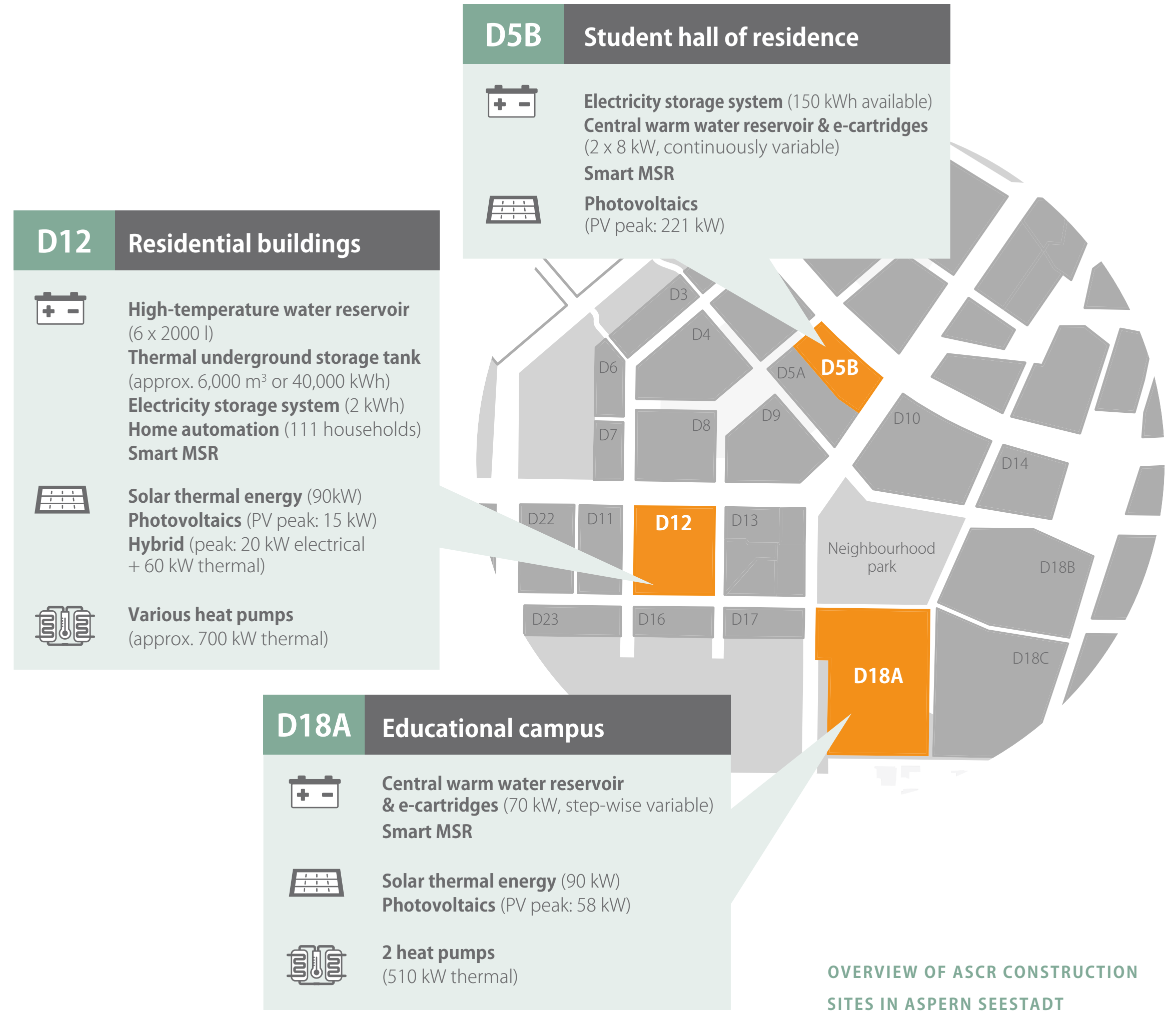
3. Offering and providing flexibility: The building plans its energy consumption so that its flexibility can be commercialised, such as on the control energy market. For this purpose, in addition to energy purchase costs, the building also takes into account price forecasts for the positive and negative availability of flexibility. This is explored in further detail in storyline 3.

In this context, the targeted outcome is to be able to quantify the extent to which energy-efficient and self-sufficient building operation can be realised through the use of renewable supply concepts and what increases in private consumption can be achieved through application of the developed systems.

Results

Installed components

To obtain meaningful results, we equipped three different types of building (see following graphic) with components on the basis of alternative energy sources, heat generators, storage systems and suitable measurement and control technology.



OVERVIEW OF ASCR CONSTRUCTION SITES IN ASPERN SEESTADT

The following components were installed in the **student dormitory** on plot D5B:

- a photovoltaic system with peak output of 221 kilowatts (kWp)
- an electrical storage system with capacity of 150 kilowatt-hours (kWh) of energy
- two cartridge heaters, each with an output of 8 kilowatts
- smart measurement and control technology

The building was constructed in compliance with the passive house standard. Heating and hot water is primarily supplied through district heating and secondarily by hot water heating elements (cartridge heaters). The latter can be used when the electrical energy generated by the building itself is available at a lower cost than district heating.

The **school campus** with nursery and primary school on plot D18A comprises the following alternative components:

- two heat pumps with combined output of 510 kW
- a solar-thermal system (90 kW)
- a cartridge heater with 70 kW output for water heating
- a photovoltaic system (58 kWp)
- smart measurement and control technology

A high-quality building envelope and a carefully thought-out system to recover heat at different temperature levels make the school campus self-sufficient in heating. This means that, even during the coldest winter periods, a sufficient supply of heat can be ensured without an additional connection to the district heating network or other backup heat sources (e.g. gas-condensing boiler). Waste heat can also be recovered from body temperature of the building's users and the operating temperature of its machines. This makes it possible to save around €10,000 per year.

The **residential building** on plot D12, which includes space for 213 rental apartments plus commercial spaces and a common garage for several residential buildings, is equipped with the following components:

- seven heat pumps with an output of approx. 700 kW
- a solar-thermal system (90 kW)
- a photovoltaic system (15 kWp)
- a hybrid system with 20 kW electrical output and 60 kW thermal output
- an underground thermal storage system with capacity of 40,000 kWh
- six hot water tanks, each with 2,000 l capacity
- an electrical storage system with capacity of approx. 2 kWh
- smart measurement and control technology

The building is completely self-sufficient in heating. The building generates energy through its solar-thermal, photovoltaic and hybrid systems (the latter being a combination of photovoltaic and solar-thermal systems) as well as heat pumps. A loop line is installed in the underground garage and acts as a hydraulic shunt. It allows heat to be generated by using the most economically effective components (above all, the various heat pumps, underground thermal storage system and solar-thermal system) and consumed directly as needed (primarily to minimise line losses).

Developing a building energy management system

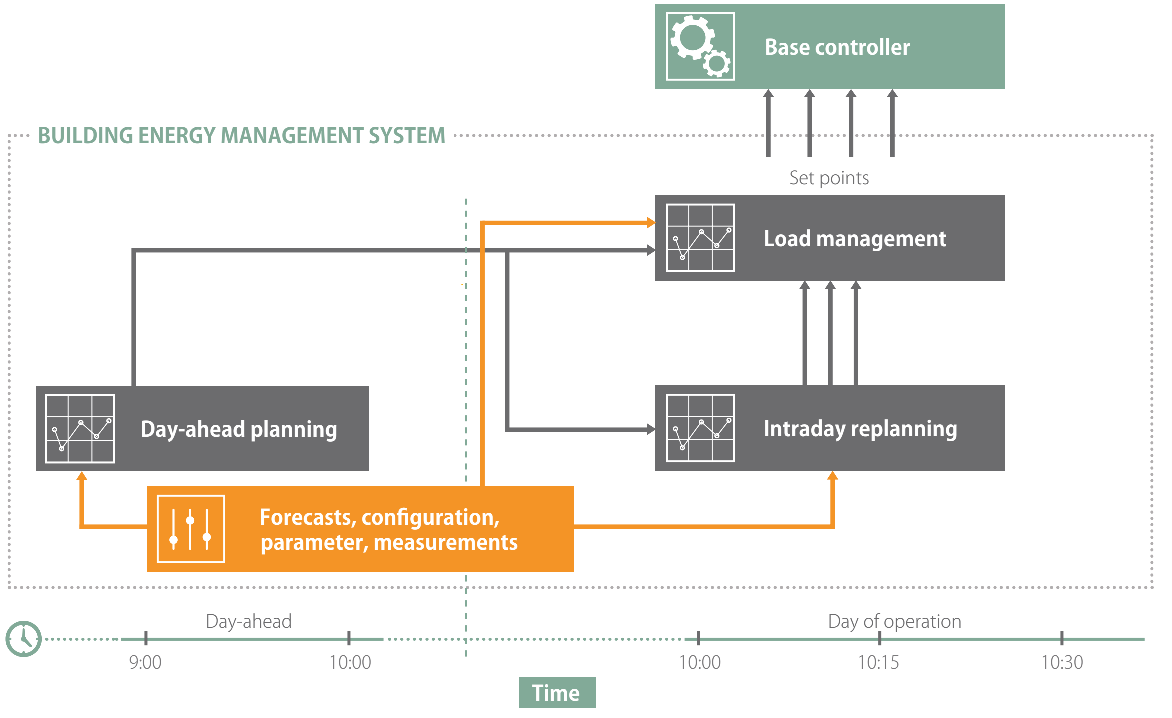
Together with all of the components outlined above, the sensors installed (e.g. to record generation, consumption and temperature values) make it possible to collect a high volume of data that can help us to gain a better understanding of both user behaviour and the behaviour of technical systems. This also enables us to quantify the savings and efficiency increases achieved in very precise terms. For example, through these measures, the components installed in the heating supply of building D12 (using self-generated eco-power) achieved an annual emissions reduction of 77 % compared to a district heating connection. The novel use of solar-thermal technology to regenerate storage systems demonstrates the extent to which the use of this input can be increased compared to conventional systems. In the residential building, the air heat pump in the residential building used air from the garage to achieve a significant increase in efficiency. Compared to a conventional gas-fired heating system, CO_2 emissions can be reduced by as much as 98 % when self-generated eco-power is used directly.

The building energy management system (BEMS), which was specifically developed in-house, played a major role in achieving these savings and efficiency increases. This system facilitates intelligent management of generation and consumption systems, taking forecasts (incl. in relation to variable energy tariffs) into consideration and thereby keeping energy costs as low as possible. In addition, the BEMS enables its users to become active participants in the energy market and also to offer services to the grid. Thus, users can contribute to grid stability and participate in energy markets. Revenues generated in this way can further reduce the costs of building operation.

A four-level control architecture was developed for the BEMS for precisely this purpose. The figure to the right illustrates the main components – day-ahead planning, intraday replanning, load management and the base controller – and how these elements interact. The forecasts for energy prices and the generation and consumption of thermal and electrical energy also draw on external information such as weather forecasts, schedules for major events and planned building occupancy levels. Planning for each next day is done the day before (day-ahead planning). A cost-optimised "timetable" is created for energy consumption and the feed-in of self-generated power into the public power grid. It is produced with a planning horizon that covers at least the next day. As these forecasts are usually not entirely correct, the plan is revisited in the course of the day ahead in intraday replanning. Depending on the specific use case, intraday replanning should react to deviations from the forecasts. If, for example, the day-ahead load profile is binding, then intraday replanning will attempt to adhere to this profile. If, however, the PV systems generate less energy than forecast, energy can be drawn from battery storage to compensate. The load and generation profiles in day-ahead planning and intraday replanning usually contains requirements for energy consumption and generation in 15-minute intervals. This interval corresponds to the smallest settlement period. To ensure these values can be met, load management must in turn re-plan at short notice and in shorter time intervals how much power the individual controllable devices in the building should consume and produce at a specific point in time. In this architecture, the base controller is tasked with ensuring all thresholds are observed. If load management planning would lead to an exceedance or failure to meet the threshold of a limit value, the base controller will correct this plan. This might happen, for instance, if plans would cause the charge level of the building's batteries to fall below the minimum permitted level.

Optimising internal consumption

Optimising the internal consumption of self-produced renewable energy (and optimising energy costs in particular) is an important aspect of economical and efficient building operation. The BEMS' operating mode that calculates a cost-optimised timetable takes into account energy consumption and generation forecasts as well as external price

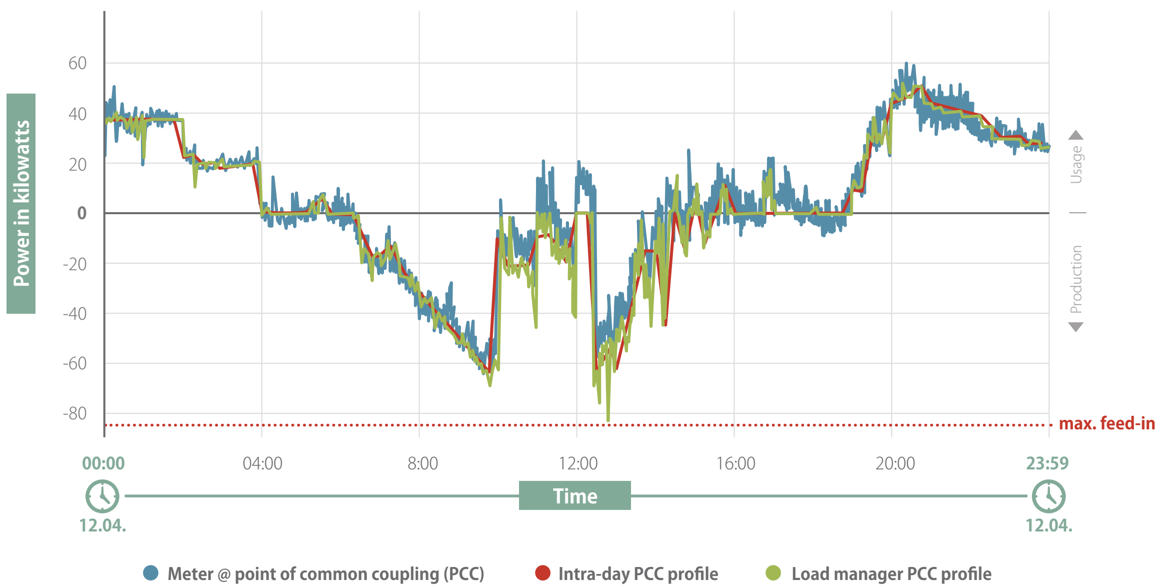


BEMS ARCHITECTURE WITH TYPICAL CHRONOLOGICAL SEQUENCE signals (for energy purchase from, and feed-in to, the public grid). This timetable is a basis for controlling the components. This planning step is revisited on a regular basis to allow reaction to deviations from the forecasts. The load manager (BEMS module, cf. previous figure) balances and compensates for short-term deviations within a planning interval.

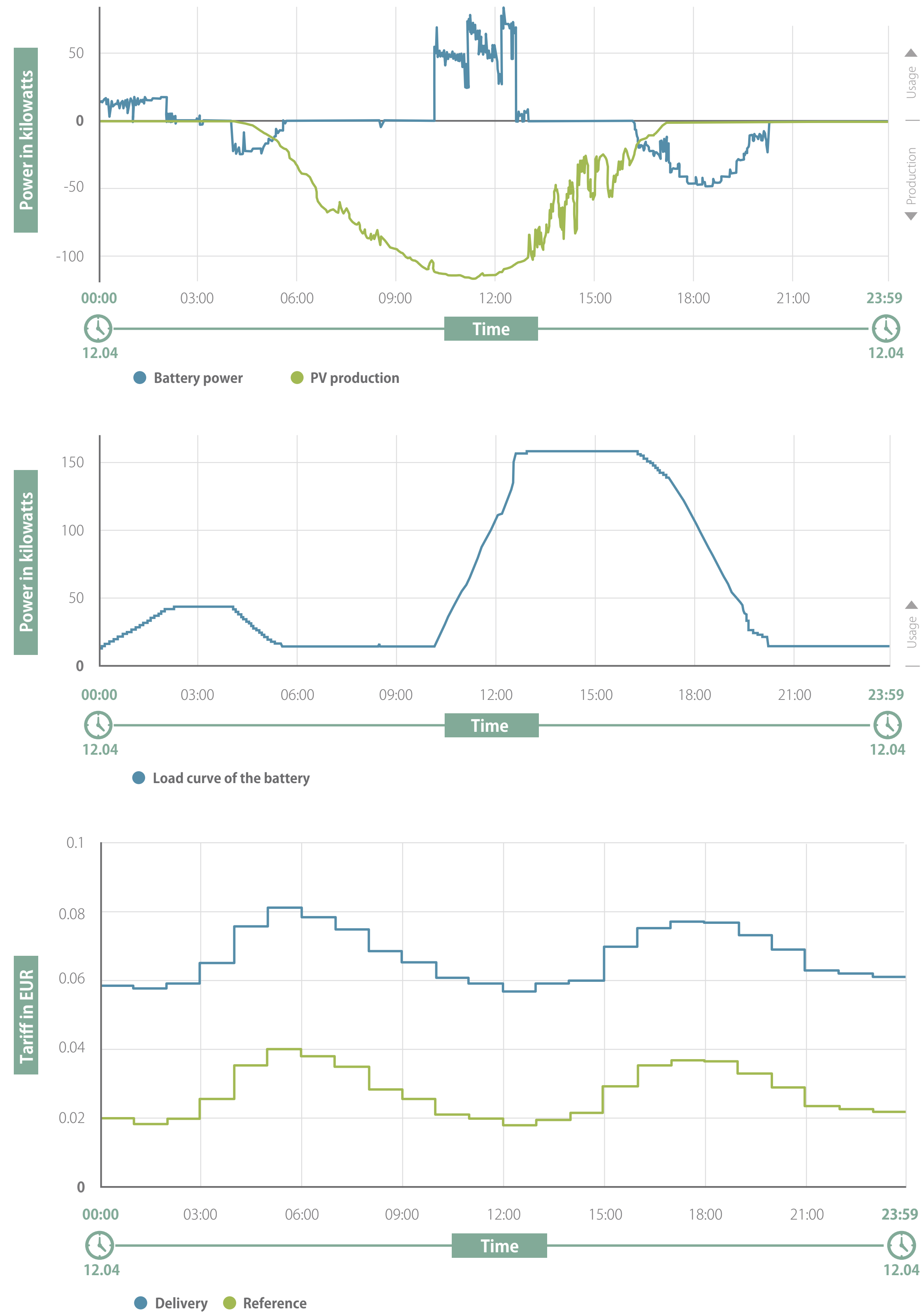
The figure below also shows an example of how system output performs at a specific point of common coupling (PCC) over the course of a day. The blue line depicts the actual performance values measured.

In the next example (see figures to the right), the hourly prices of Energy Exchange Austria (EXAA) are displayed with a forecast of power production by a photovoltaic system (PV system) to control the charging or discharging energy of an electrical storage system. The optimisation software comprises different modules that take different control intervals and planning horizons into account. Although the results may vary significantly on individual days, depending on the forecast quality and weather conditions, the field test clearly showed that the system offers a substantial advantage in optimisation. The cost savings compared to normal operation depend heavily on the selected tariff structure and quality of forecasting. Furthermore, there is greater potential for optimisation in the winter months than in the summer months. The achievable optimisation potential can only be quantified in the form of possible bandwidths for individual buildings.

If the costs of the BEMS and the measurement and control technology required are less than the achievable returns from optimisations over the long term, promising economic potential can be expected in the long term (provided that existing and future buildings are fitted out accordingly). However, this should always be examined in each specific case, first and foremost because the relation between the controllable component output (e. g. electrical output of heat pumps) and the cost of the BEMS and the measurement and control



OUTPUT PROGRESSION AT A SPECIFIC POINT OF COMMON COUPLING (PCC) FOR ONE DAY



OUTPUT PROGRESSION FOR POWER GENERATION AND STORAGE SYSTEMS AND EXTERNAL ELECTRICITY PRICES ON THE EXAA

Application example of a building energy management system

The energy supply system for residential building D12 is highly complex. However, the field test has confirmed that its efficiency can be significantly increased and that even large-scale buildings in urban locations can cover their internal energy requirements without district heat or gas connections. This depends entirely on the availability of alternative energy sources. The complexity of these systems represents a new type of challenge for building contractors. The BEMS developed in ASCR, which adjusts all components to one another and optimises their use, can be of assistance. It will allow building operators to operate their buildings markedly more flexibly in future with little effort required for configuration. In addition to electricity, heating, cooling and ventilation systems, the BEMS can also take flexible energy tariffs, power grid requirements (timetables and participation in the control energy market) and weather forecasts into account. This will make it possible to generate revenues by using as yet unused potential.

technology has a significant impact on the benefit-cost ratio.

In this context, the additional costs incurred by the installed power generation and storage systems can be covered in the student dormitory by moderate rent increases for single-occupancy rooms. The cost of a PV system alone would be balanced out by an increase of 1.5 % or €6 in monthly rent. To finance a PV system including an electricity storage system, the monthly room rents would have to be increased by 3.5 % or €14. In an ideal scenario, these additional costs would be reduced by surplus revenues (internal consumption revenue minus future costs of the BEMS and the measurement and control technology). However, we currently lack the long-term experience needed to estimate this aspect accurately.

Summary and outlook

In technical terms, the operational experience gained and the optimisation solutions developed in ASCR can already be applied in buildings that have been equipped accordingly. The main findings can be summarised as follows:

- Providing high flexibility in building technology on the basis of renewable energies delivers emissions savings.
- The waste heat from underground garages, people and machines can be used sustainably.
- Solar-thermal technologies have significant benefits for low-temperature applications.
- Components can only deliver the desired results when well adjusted to one another.
- When implemented, optimisation measures make it possible to markedly increase internal consumption of self-generated energy. In doing so, however, the results of optimisation efforts are significantly influenced by external factors such as weather forecasts and tariff forecasts.

In any case, future developments – such as the growing pressure to implement low-emission urban construction – will generate increased interest in alternative energy supply concepts. The solutions developed in the R&D programme offer an important tool for establishing energy-efficient and self-sufficient buildings. The building energy management system (BEMS) is already capable of intelligently managing complex energy systems and, in doing so, deliver cost benefits for building operators. Furthermore, the experiences gathered in installing and commissioning these systems can also be made available to interested building contractors. Efficient measurement and control systems with the lowest possible maintenance requirements will play a central role over the long term.

3

Managing building optimisation and flexibilities

ASCR use cases 3 to 7, 10 and 11 investigated how customer integration and proper management of building optimisation systems could be used to exploit flexibilities in buildings for grid-friendly and market-friendly purposes. This involved establishing a "virtual power plant" that can aggregate distributed power generators and consumers and offer their aggregated capacities on different markets. The experiences gathered show that buildings equipped with intelligent systems, combined with a virtual power station, can already provide useful services – and that these buildings will be able to exploit economic potential over the long term that has so far gone untapped.

Motivation and objectives

An important aspect of building optimisation, assessing the issue from a business perspective, on the one hand, is to maximise private consumption of self-produced renewable energy and to minimise energy costs (cf. also storyline 2). On the other hand, with the energy system currently in a state of flux, there is an increasing need to operate electro-thermal systems in urban building infrastructure (variable consumers, generators, storage units) with sufficient flexibility that they can also be used to serve the public power grid and the energy market.

To achieve this, the ASCR R&D programme found it initially necessary to develop a building energy management system (BEMS) that could use the available flexibilities in the buildings. These flexibilities are used to optimise building operation on the basis of different parameters. One of these use cases aims to aggregate existing building flexibilities and exploit their commercial value externally, e.g. on the control energy market. For this purpose, the building also takes into account price forecasts for positive and negative flexibility capacities as well as energy purchase costs.

The solution developed in ASCR is based on the concept of a virtual power plant (VPP). Early ASCR projects (e.g. Austrian projects such as INTEGRA or Virtual Green Power Plant) have already addressed the topic of virtual power plants and defined them as follows:

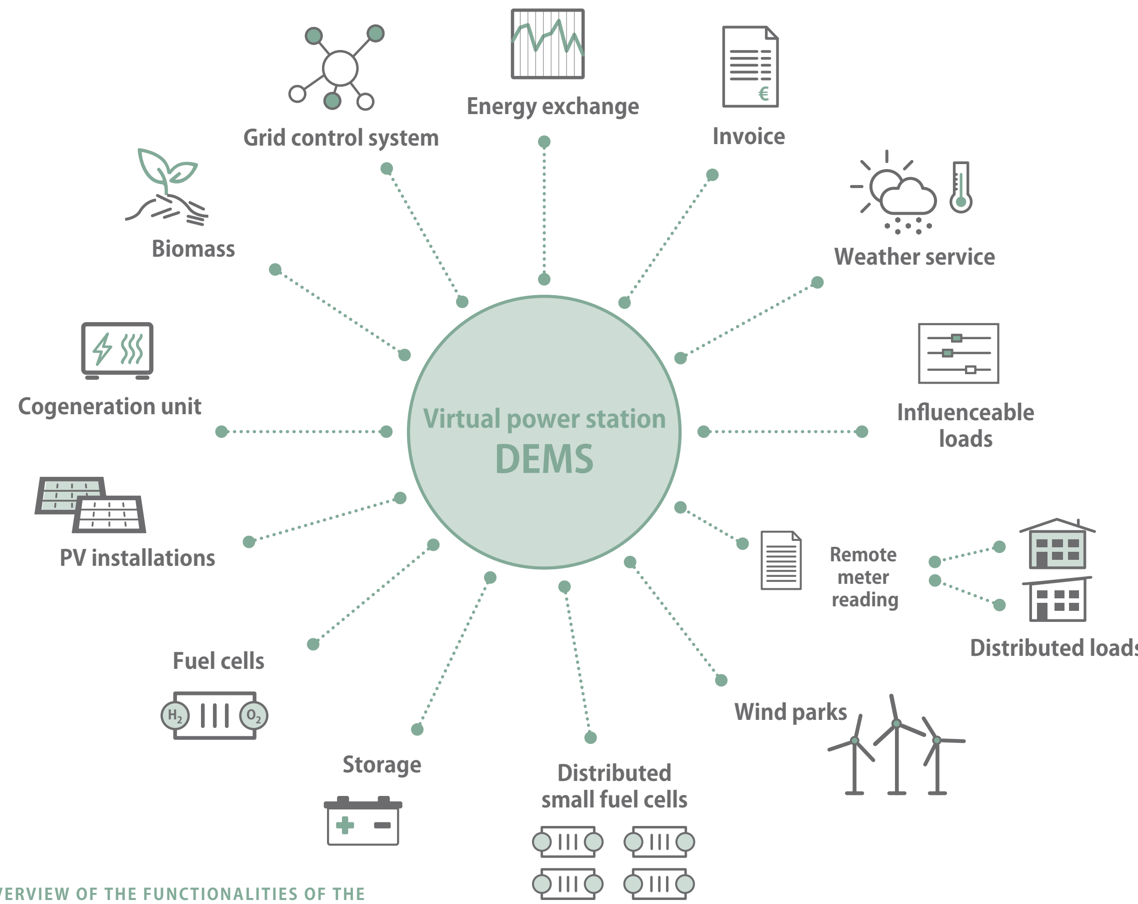
A virtual power plant is an entity that can aggregate distributed generators and consumers and offer them on different markets as an aggregated power plant.

Virtual power plants can act supra-regionally and independently in existing supply regions. This means that different contract customers (e.g. electricity consumers, generators or storage system operators) can enter into agreements with different virtual power plants in a physical grid segment.

The fact that virtual power plants can operate at a supra-regional level means that an operator of a virtual power plant can sign up supra-regional partners in different grid segments. The optimisation targets set by the operator of a virtual power plant determine their operational strategy. Conceivable strategies might include, but are by no means limited to, the following outlines:

- Trading on the electricity exchange (day-ahead, intraday or futures markets)
- Direct marketing (over-the-counter contracts, OTC)
- Providing control energy (secondary and tertiary control energy market)
- Avoiding balance energy in balancing groups (compensation for incorrectly forecast volatile generation)
- Avoiding peak loads and grid overloads
- Optimising private energy consumption, such as for buildings or e-cars

In this context, it is important to note that the operator of a virtual power plant usually only has information about their contractual parties and uses this for their strategies for marketing available flexibilities. The operator does not have access to further information, such as that about the consumption and generation behaviour of other "prosumers" (i.e. customers who not only consume but also generate power themselves in the grid, such as through a photovoltaic system). Therefore, the operator of a virtual power plant cannot take the regional grid situation into account in their marketing strategy. Grid operators are also not aware of planned changes in the generation or consumption of energy (timetable changes) that could be caused by the virtual power station. Unexpected peak loads can occur as a result, such as when numerous fast-charging infrastructures for e-cars are activated at the same time. As a result, this storyline quantifies the extent to which services can be provided to markets and power grids using existing supply flexibility in buildings in combination with virtual power plants. This aspect is explored in detail in the following sections.



OVERVIEW OF THE FUNCTIONALITIES OF THE DECENTRALISED ENERGY MANAGEMENT SYSTEM – DEMS

Results

The required standard functionalities of virtual power plants (primarily to realise the operational strategies described above) were realised in ASCR on the basis of the decentralized energy management system, or DEMS for short (cf. figure above). This is composed of two sub-systems: the DEMS designer, which is a graphical data entry tool, and a runtime system complete with operator interface. The system can compensate for major short-term variations in power generation and consumption and can therefore be used on the control energy markets. The energy management system communicates with the connected power generators, loads or storage systems in accordance with IEC 60870-5-104, a communication standard in infrastructure automation, which means that no additional software is required. The parameters of the communication connection and the system connection in combination with the DER (distributed energy resources) controller are also stored in the DEMS designer. These are available in the runtime system immediately after activation.

The new solutions developed in ASCR expand these standard functionalities with tailored interfaces and algorithms between the virtual power plant, BEMS and grid operator, which facilitates coordinated optimisation of the system as a whole. For example, the BEMS can amend the planned timetable for one or more buildings on the day before, when it takes requirements and forecast data provided by the virtual power plant into account in relation to self-generation and electricity prices.

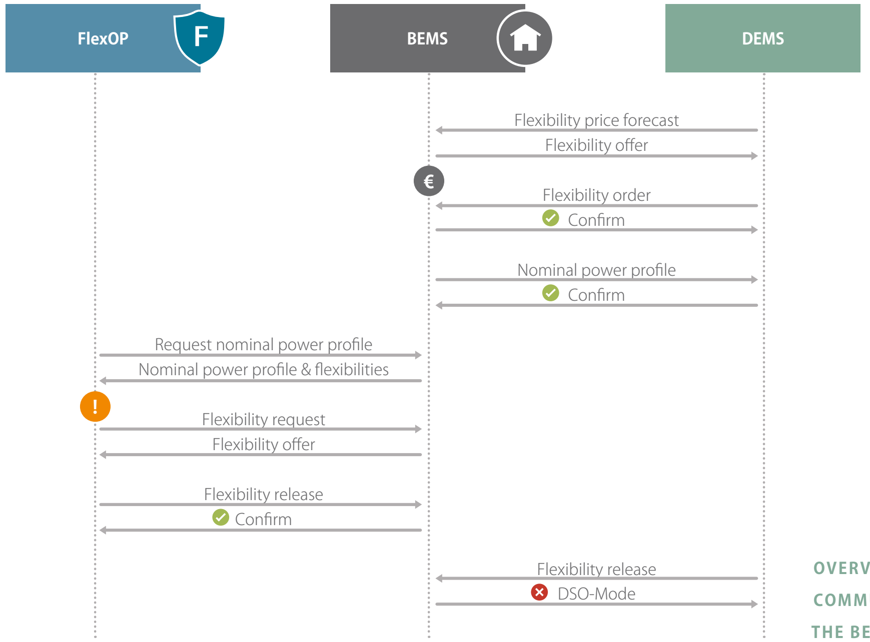
Furthermore, the introduction of a flexibility operator (FlexOp; cf. also storyline 4) in ASCR ensures that the timetables produced by the BEMS avoid violating any regional grid restrictions wherever possible. Violations of this type could compromise secure grid operation. The FlexOp developed in ASCR thus expands a virtual power plant by providing forecasting capabilities for the load progression of all customers in a grid segment.

The figure below illustrates a typical communication sequence between a building (represented by the BEMS), the VPP (realised through the DEMS, which aggregates flexibilities for commercial purposes) and the flexibility operator (FlexOp), which uses flexibilities to stabilise the distribution grid. The expansions to the virtual power plant developed in ASCR therefore make it possible to trade flexibilities with both supra-regional market players and local grid operators and to charge them accordingly.

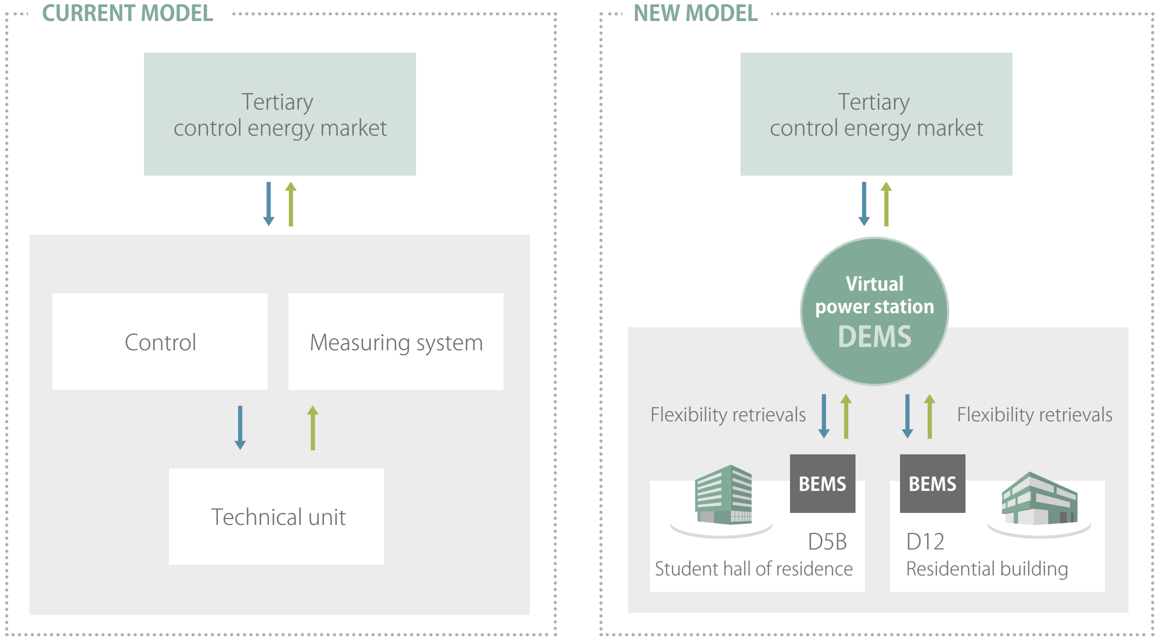
New concept for the commercialisation of flexibility

During the course of the project, a new model was also developed and tested in which a VPP bundles together individual flexibilities (e.g. in different buildings). Until then, flexibilities had only been combined in individual technical units (such as an isolated photovoltaic system or a single wind or gas turbine) that often deliver high electrical outputs. In doing so, the VPP individually controlled and billed for these units. One building may nevertheless have a variety of different units (e.g. heat pumps, PV systems or batteries). These units deliver relatively little output and are often subject to highly specific framework conditions (see graphic above). So, such an approach would not be practical, primarily due to costs involved (many components required, and high operating costs).

For this reason, a new model was developed (cf. graphic above) built on the idea of flexibilities in a building can be abstracted by a single interface and independently managed within the building. To do this, the BEMS takes specific optimisation targets into account and calculates the flexibilities available in the entire building and offers these to the DEMS in aggregate. During a retrieval and when flexibility is available, the BEMS then decides which units it wishes to draw on to compile the desired flexibility (e.g. operating reserve). This facilitates optimal management of the units in the building and reduces complexity for the higher-level DEMS.



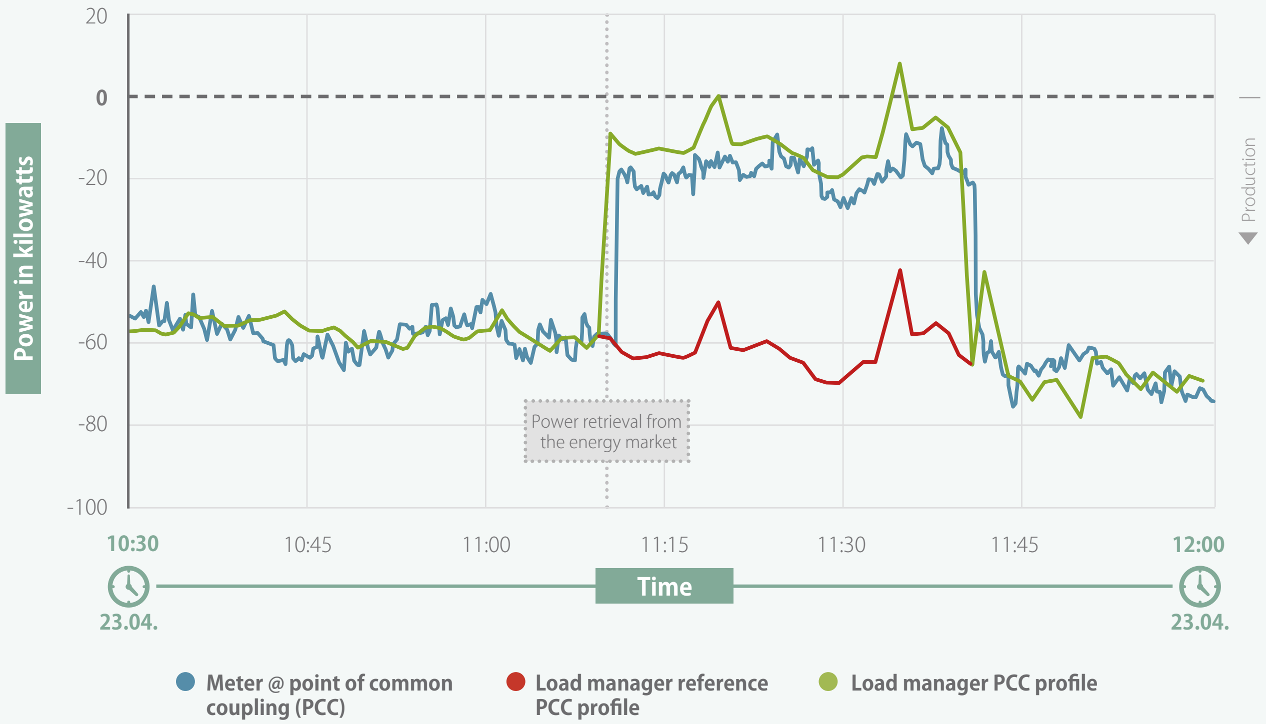
OVERVIEW OF AN EXEMPLARY COMMUNICATION SEQUENCE BETWEEN THE BEMS, DEMS AND FLEXOP



COMPARISON OF THE COMMERCIALISATION OF FLEXIBILITIES ON THE TERTIARY CONTROL ENERGY MARKET BEFORE AND AFTER ASCR R&D ACTIVITIES

Aggregation of building flexibilities

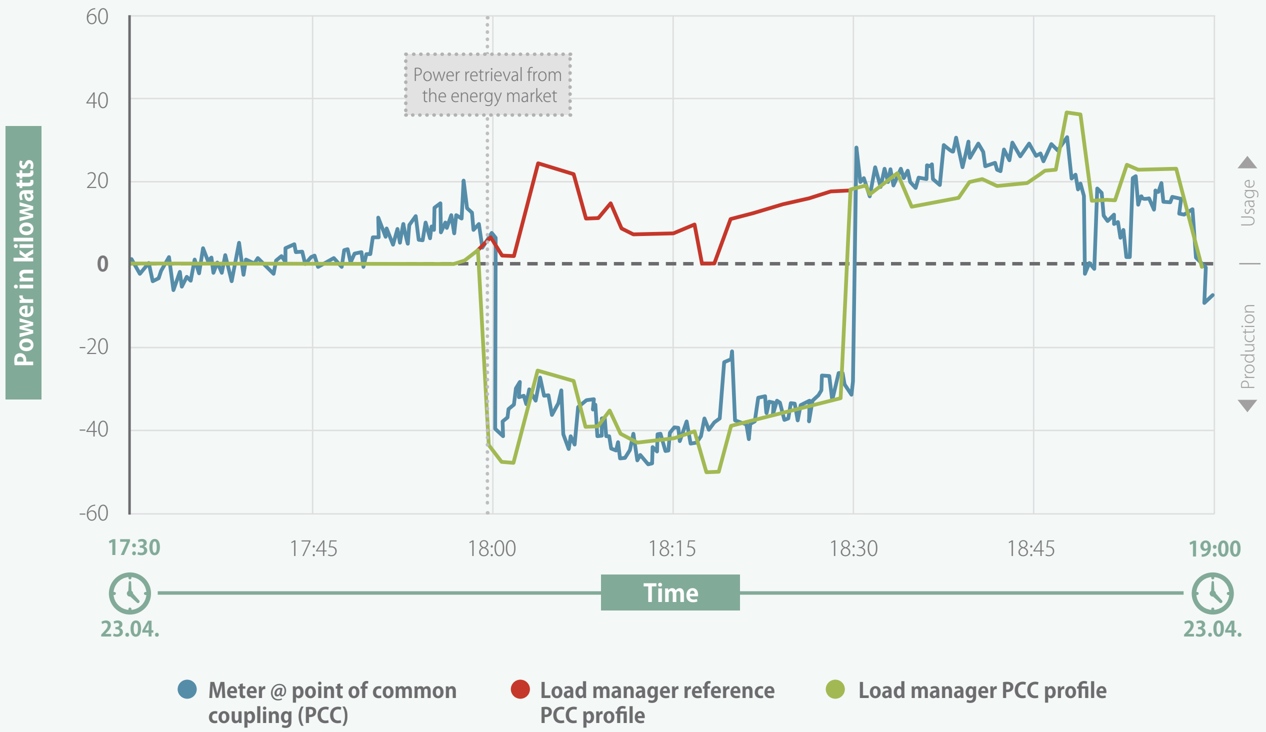
Example application to activate building flexibility



NEGATIVE CONTROL ENERGY AVAILABILITY
IN THE STUDENT DORMITORY

To demonstrate ability of the developed solutions to participate in the control energy market, we can examine examples of both positive and negative flexibility, e.g. of the student dormitory.[1]. "Positive flexibility" means that additional power is generated by the virtual power plant. In contrast, "negative flexibility" means that the power generated by the virtual power station is reduced and/or that the power consumption of systems and devices that can draw on its power is increased. The figures show output progression at the point of common coupling. The graphic on the left shows negative availability (from the perspective of the virtual power plant), while the graphic below shows positive availability. In both graphics, the "load manager reference PCC profile" is the reference for the retrieval. The "load manager PCC profile" represents the direct specification set by the building optimisation system (BEMS) as the sum of the individual components' timetables. Ultimately, it is important to recognise that actual measured output progression ("meter @ PCC") follows the specifications of the BEMS and that flexibility can be activated accordingly. The short-term variations in availability are caused by low-level fluctuations (such as a cloud passing over a PV system) and are not relevant for calculations due to their brief nature.

In addition, in order to estimate the market potential in Vienna (assuming that 20 % of building stock will be usable in future), the results of initial calculations indicate that annual profits of up to € 30 million could be generated if each building offered 30 kW of secured output (i.e. a total of approx. 1 GW across Vienna) on the negative tertiary control energy market. In this regard, however, it is crucial to consider that a significant increase in the offered (and therefore available) output on the control energy market may lead to a fall in prices, which could result in the potential profits being reduced.



POSITIVE CONTROL ENERGY AVAILABILITY
IN THE STUDENT DORMITORY

1 This functionality will also be realised in prototypical form in the residential building in the near future.

In short, from where we stand today, the product developed in the course of the ASCR R&D programme is already capable of offering a virtual power plant the following functionalities:

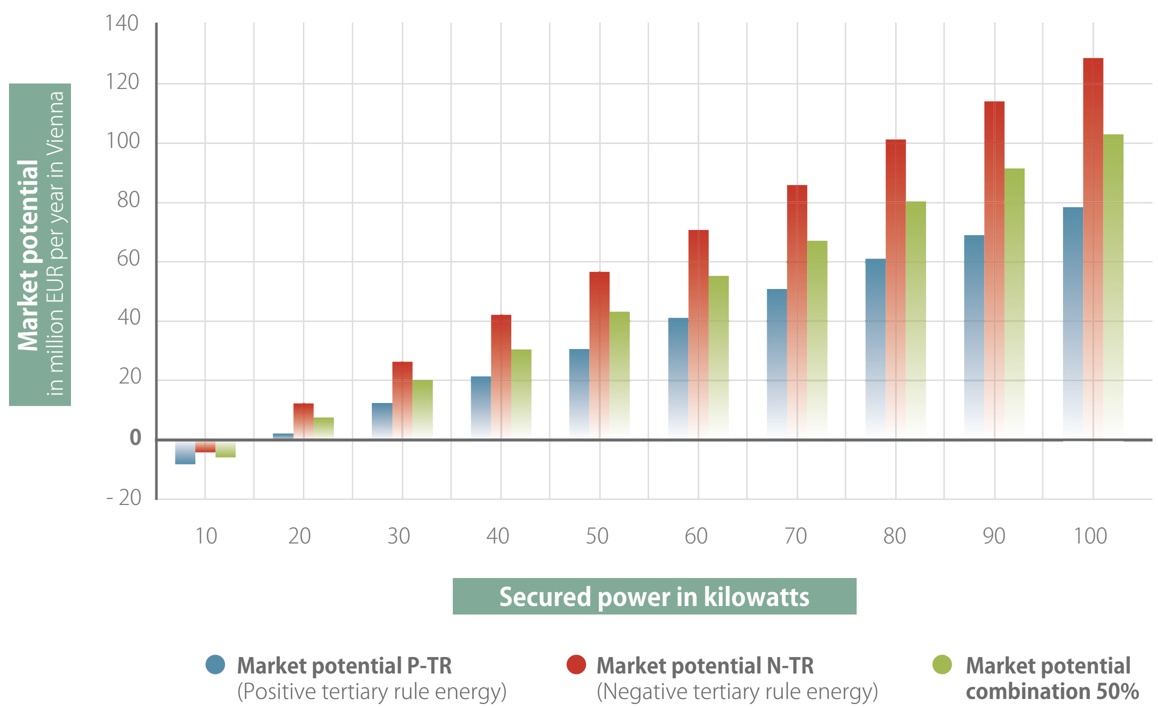
- Integration of customer requirements (e.g. through temperature settings, controlled via smartphone, cf. storyline 1) in the building optimisation system (BEMS), which represents a direct interface to the virtual power plant.
- Aggregation of numerous individual buildings (e.g. residential complexes, schools, offices, etc.) to form a collective that can be used in coordination for grid-friendly purposes (e.g. to avoid grid overloads) or market-friendly purposes (e.g. for trading on the control energy market). This is made possible by expanding the existing VPP solution (DEMS) with suitable interfaces and algorithms to connect to the building optimisation system (BEMS).
- Viability of suitable communication interfaces in order to meet the requirements of grids (e.g. short-term consumption reduction or "short-term load shedding") or markets (e.g. time-based requirements subject to pre-qualification conditions of control energy markets).

Market potential

A case study was also defined for the functionalities developed to use flexibilities, with the aim of presenting the potential costs in relation to the realisable benefits. To do this, the costs of the components needed for different construction sites/buildings to participate in the control energy market were compared with the achievable revenues.

The following parameters were used and assumptions made to do so:

- Costs of DEMS, remote control unit and data transmission per building = € 520 p.a.
- Revenue per kW (estimated by Wien Energie) for use on the negative tertiary control energy market = € 29 p.a.
- Revenue per kW (estimated by Wien Energie) for use on the positive tertiary control energy market = € 44 p.a.
- Number of buildings in Vienna = 164,745 (Data: Statistics Austria); to estimate the market potential for control energy use, it is assumed that 20 % of buildings will be equipped accordingly in future



OVERVIEW OF THE THEORETICAL MARKET POTENTIAL IN VIENNA BASED ON THE GUARANTEED OUTPUT PER BUILDING (P-TCE = POSITIVE TERTIARY CONTROL ENERGY; N-TCE = NEGATIVE TERTIARY CONTROL ENERGY)

The chart opposite depicts the theoretically realisable profits, subject to variations in the guaranteed capacity available on the control energy market. However, it is important to repeat in this regard that a significant increase in the offered and therefore available output on the control energy market may lead to a fall in prices, which would reduce the potential profits.

Summary and outlook

The solutions developed in ASCR mean that new instruments are now available to energy suppliers and grid operators, enabling them to activate and commercialise as yet unused flexibility in urban buildings. These instruments are made available primarily through the refined concept of a virtual power plant. The decentralized energy management system (DEMS) is a specific product, the functionalities of which performed very well from a technical perspective in the field tests. The demonstrated potential for economic returns substantiated in a use case also raise hopes that the new functionalities of virtual power plants can be used to a greater extent in urban buildings. The field tests carried out to date, however, have not yet accumulated sufficient long-term experience of seasonal changes (different characteristics in summer/winter) or demographic developments (changes in customer structure). In particular, the activatable flexibility (guaranteed capacity and shifting scope) and the resulting long-term potential for economic returns in an urban environment are factors that still create risks. Further experience should be collected and interpreted in further research activities.

4

The development of low-voltage grids in urban areas: the smart grid migration path

ASCR use cases 1, 2, 5, 6 and 8 to 10 concern the prototypical implementation of a so-called "smart grid migration path". After the use of various sensors in step 1 of this migration path has brought transparency to the distribution grid, subsequent data analyses in step 2 already allow us to identify potential increases in efficiency in the operation of distribution grids. In addition, planning and operation processes supported by automation can also be implemented to a greater extent in urban grid areas. A key challenge is digitalising distribution grid operation in step 3 of the migration path.

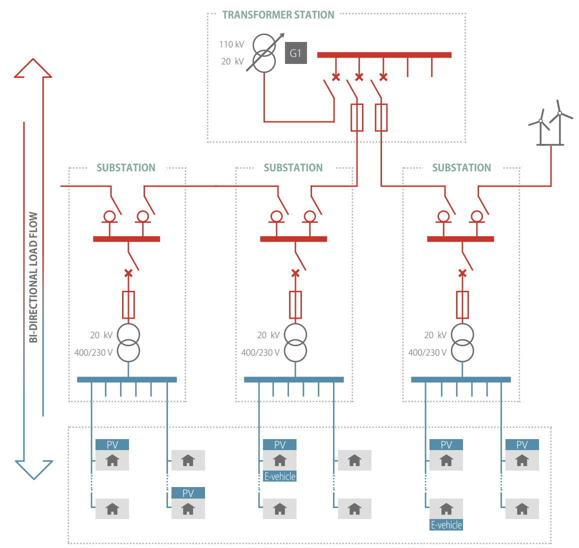
Motivation and objectives

Existing solutions, such as controllers to integrate renewable, volatile and decentralised power generation or demand side management in the smart grid field, have already been examined in earlier ASCR projects.[1] Examples include the national DG-DemoNetz series or INTEGRA. These projects generated solutions to the following problem: The term "energy transition" has become a buzzword often used to describe the challenges that new developments pose to distribution grid operation, above all the growth of renewable energies and the decentralisation of energy supplies. The following graphic therefore only gives an indication of this.

Grid operators are already experiencing the implications of this evolution, a selection of which can be summarised as follows:

- The rules of grid design are losing their applicability.
- Decentralised generation systems cause localised voltage increases (voltage problem).
- Fluctuating generation and highly dynamic energy prices present new requirements for grid infrastructure.
- Too many electric cars on one line can trip a line fuse (current problem).
- Decentralised generation in combination with electric cars can result in result in thermal overloads in individual sections of cabling.

1 ASCR joint venture partner Siemens was primarily involved in these projects: the smart grid concepts developed and tested for rural medium-voltage and low-voltage grids (in the grid regions of Salzburg Netz GmbH, Netz Oberösterreich GmbH and Vorarlberg Netz GmbH), although they can also be applied in urban areas (such as the grid region of Wiener Netze).



TRANSFORMATION OF PASSIVE DISTRIBUTION GRID OPERATION TO ACHIEVE SMART GRID OPERATION WITH BIDIRECTIONAL FLOW OF LOADS AND COMMUNICATION

Consequently, distribution grid infrastructure must be operated closer to the limits of its capacity in future to continue to ensure an efficient and affordable energy supply. The required optimisation of the network operators' operating and planning processes is therefore a key focus for the future development of distribution grid infrastructure, towards a smart grid.

The ASCR R&D programme makes it possible to test the steps required to implement smart grids in urban areas. In Seestadt, a large urban expansion zone in north-east Vienna, work is underway to research efficient solutions for the cities of the future.

ASCR's methodical approach, however, focused less on developing new control algorithms than on analysing the potential benefits from "plug & automate" topics and on improving the robustness of existing solutions for a smart grid migration path. The core research topics are divided into the areas of grid monitoring, data analysis and active grid management.

The migration path should serve as a guideline to increase planning security in a rapidly changing environment and to make visible the efficiency gains achieved by distribution grid operators through the use of new technologies. The ASCR R&D programme is the first to offer the opportunity to conduct research into the key steps for the implementation of intelligent and economically feasible distribution grids in an urban context. The insights gained will be used to develop generally applicable solutions in a subsequent research phase.

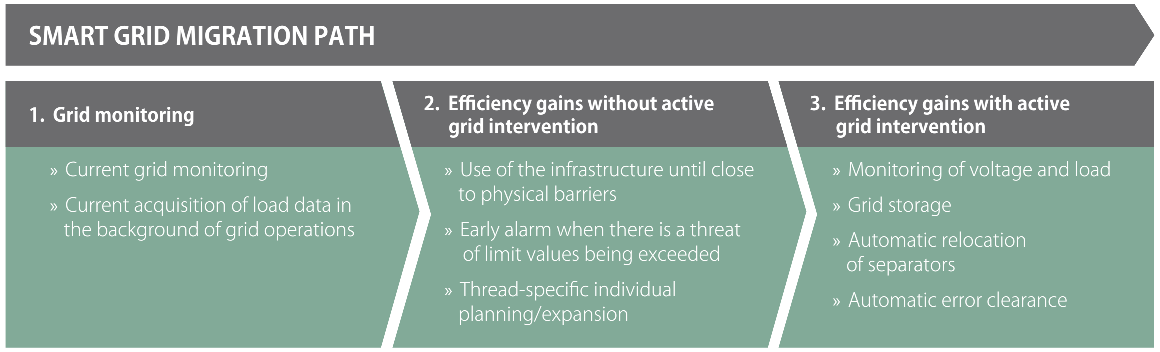
Results

Smart grid migration path

To be able to overcome the challenges described in the previous chapter and securely use the reserves available, it is firstly necessary to examine the distribution grid in detail. To do this, we need to implement an efficient data logging system coupled with intelligent data preparation (step 1).

This data can then be used in corresponding analyses to gain insights for the structure of future

SCHEMATIC DEPICTION OF THE ASCR SMART GRID TEST BED



THE THREE-STEP SMART GRID MIGRATION PATH

planning and operation processes in distribution grids and derive scenarios for future development (step 2). In selected areas and to an optimal extent in terms of the benefit-cost ratio, active grid interventions can increase potential efficiency (step 3, see graphic above).

Step 1: Monitoring as the basis for future smart grid use cases
The basis of all smart grid activities, both today and in the future, is a monitoring concept tailored to each use case that determines current grid condition, including all downstream data preparation and validation activities. Particular attention is given to installing field sensors that are as self-configuring as possible and to ensuring that sensors are effectively allocated topologically (static and dynamic). To do this, a corresponding grid monitoring system with power-quality measuring devices and grid monitoring devices (GMD) was installed to collect, process and interpret of information on grid conditions with a sufficient degree of precision. Field tests have also shown that, depending on the application, it may also be sensible to ensure the required data quality and integrity as close as possible to the source.

The ASCR smart grid test bed comprises the bulk of the low-voltage distribution grid in the south-east area of Seestadt. This includes twelve grid stations with 24 transformers. Each of these grid stations, including their subordinate grids, was equipped with an extensive monitoring infrastructure. The figure to the right shows the different measurement devices used and the installation variants. The GMDs were predominantly installed in Wiener Netze connection boxes and loop boxes (see graphic, right). This involved installation of the following components:

- **Low-voltage circuit breaker with definite-time overcurrent protection**
  An overcurrent release system is coupled with the low-voltage circuit breaker. In the event of a fault, the circuit breaker trips locally in the grid station and thus prevents the fault from spreading. The integrated sensors measure the current, voltage, power and energy. This data can be read on-site. In the smart grid test bed, each transformer is equipped with the circuit breaker and the accompanying measurement module.

- **Power quality (PQ) measurement**[2]
  The PQ measuring devices are installed in front of the low-voltage circuit breaker and serve to measure power quality at that point. Mobile PQ measuring devices were installed at times to facilitate a qualitative comparison (benchmarking) between between different transformer technologies.

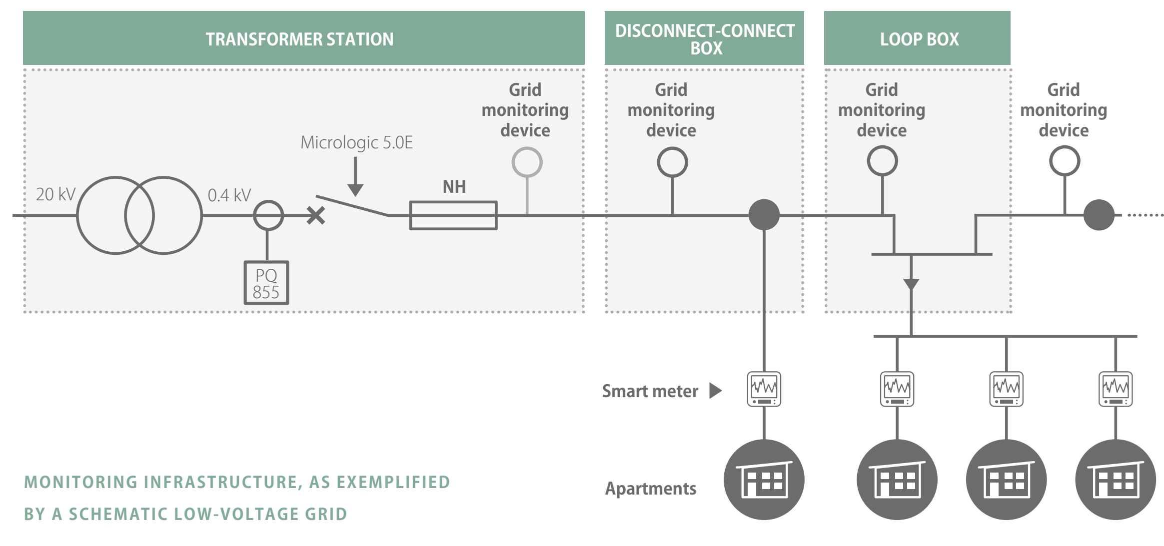
2 The power quality in electrical grids provides information about supply availability (e.g. number of power outages per year), voltage quality (any deviations from nominal voltage; e.g. 230 volts) and the stability of the supply frequency.

- **Transformers**
  A total of 24 transformers were installed in the test bed. Innovative technologies were installed in 15 transformers. These technologies include a voltage-regulated distribution transformer (VRDT), transformers using plant oil (Midel) instead of mineral oil for cooling processes, transformers with an amorphous core and transformers with aluminium rather than copper windings. Distribution grid operator Wiener Netze has not yet used such technologies.

- **Grid monitoring device (GMD)**
  In principle, GMDs were installed outside the grid stations in the loop boxes and connection boxes of the low-voltage grid. Another variant is also shown in the figure below. This variant is used on building sites not supplied by low-voltage grids that correspond to the target grid specifications of Wiener Netze. This is usually a radial network with stubs that is installed by an electrical installation company commissioned by the building contractor. Another alternative is supplying electricity directly from the transformer station. In both cases, the GMD is installed directly on the grid station's secondary wall to ensure that the measurement technology can function consistently. The integrated "unavailable data handling" module also ensures that missing measurement data is estimated well enough to enable downstream applications to operate reliably.

A further finding in connection with the strict data privacy requirements in force in Austria is that the installed measurement devices are not expected to be replaced in future as part of the roll-out of smart meter systems. This is due to the lack of customer acceptance, which means that high-resolution data cannot be used to the full extent. Only about 10 % of customers have consented to this data being accessed. The use of new infrastructures to be constructed for various applications (synergetic use) – which would be sensible from an economic perspective in particular – is therefore impeded or at least restricted to the shared use of ICT infrastructure.

Step 2: Data analysis and interpretation
In step 2 of the migration path, numerous evaluations were carried out on the collected data for the purpose of quality management, operational support and benchmarking. This work prepares a system for data-based grid planning and operational management (step 3 of the migration path). Today, grid planning is still based on values collected from



MONITORING INFRASTRUCTURE, AS EXEMPLIFIED BY A SCHEMATIC LOW-VOLTAGE GRID

Use case Monitoring infrastructure in street lighting

The street lighting installed in Seestadt was examined in detail to answer to different questions. The shareholders were specifically interested in:

01 the potential effects of widespread use of modern LED street lights on the quality of the distribution grid,

02 the analysis of realised and potential savings from the use of different operating methods, and

03 public satisfaction with street light brightness and choice of colour, and their subjective feelings of safety.

- The study began with an analysis of different reference projects within Europe. The findings of these projects were the basis for the research activities that followed. The City of Salzburg was found to be particularly innovative. It greatly reduced light smog and conserved energy with its "StadtLicht 2020" (CityLight 2020) and "Bewegungsgesteuertes Licht" (Motion-activated lighting) projects.

- During 2018, the actual energy and power demand for lighting in Seestadt was recorded in the context of power quality measurements (using the monitoring infrastructure described previously). Taking these measurements as a basis, it was possible to precisely calculate the operating hours and energy demand over the course of a year. As the use of LED street lighting makes it possible to reduce the intensity of lighting by around half in the off-peak hours from 10 pm to 6 am (limited operation), this delivers annual savings of around 22 megawatt hours (MWh) in Seestadt alone. This corresponds to a 26 % reduction in demand, which in turn produces energy cost savings of roughly € 3,000. If all 244,000 street lights in Vienna were fitted with light-emitting diodes (LEDs), this would deliver energy savings of 5,400 MWh or € 650,000 per year.

- A sociological survey in Seestadt clearly showed that around 60% of those surveyed considered the street lights installed by the responsible municipal department (MA 33) as good or pleasant.

- It could be important for future developments to determine the potential of demand-oriented lighting (e. g. street lights only illuminate a street when needed). However, the measurements show that such measures would only contribute further savings of approximately 10 %. At the current state of technology, this does not (yet) justify the increased procurement costs of the required sensor technology (comparable to motion sensors in living areas) or the resultant maintenance costs.

the past experience of the grid operator. In ASCR, a threshold analysis was developed as a central application to conduct automated examinations of the data generated in the test bed each day on the basis of freely parametrisable criteria. Any threshold exceedances were compiled as "events" and made available to the grid planner or grid technician. Based on critical violations of limit values, the load situation can, on request, be transferred into a grid planning tool. This tool enables the grid planner to use real data to identify a solution, such as by amplifying the power line capacity or installing automation technology.

However, step 2 can also be applied to decentralised, distributed systems. Various support functions can be put in place to facilitate the active grid interventions required in step 3. These functions above all help to ensure the most autonomous and robust operation possible. The solutions required (switch state detection, grid state forecasting, adaptive assignment modules and the grid watch dog) can be developed in ASCR. In the course of this research project, it became clear that, for the necessary components to be practicably integrated in distribution grids' daily operational management processes, "plug & automate" functionalities – comparable to the self-configuration process of a USB stick when inserted into a computer – are absolutely essential (see box, right).

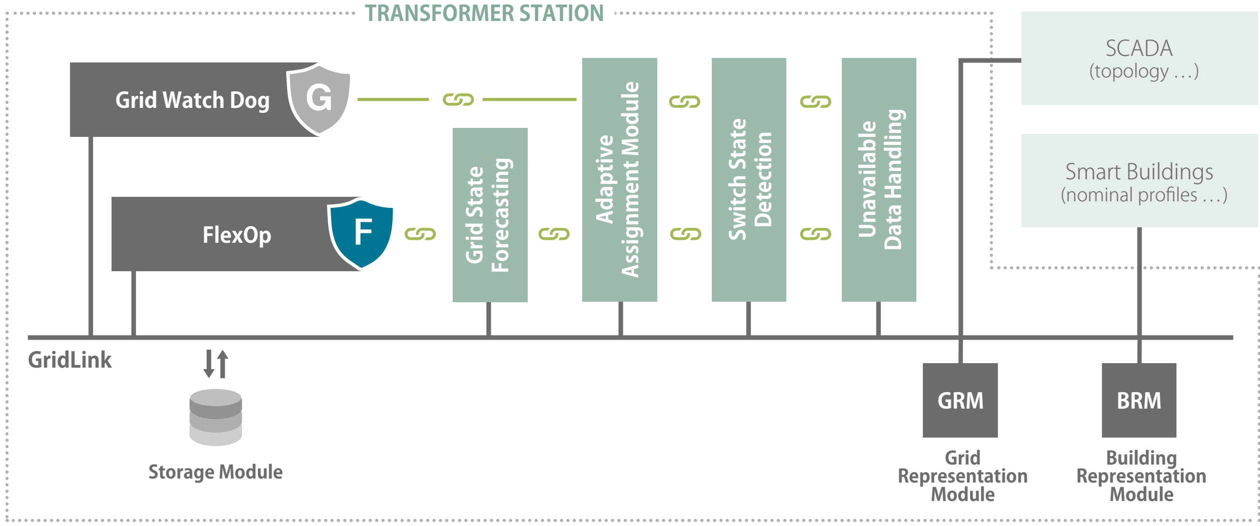
Step 3: Active grid management

The graphic overleaf summarises all applications of an urban and active low-voltage grid management system developed and validated for step 3 of the smart grid migration path. GridLink is the basis for this; it facilitates the data exchange, a storage module for decentralised data storage, a grid representation module (GRM) and a building representation module (BRM). The switch state detection (SSD) software module equalises grid topology, while the adaptive assignment module (AAM) allocates individual smart buildings to grid node points. Grid state forecasting (GSF) creates an intraday forecast for expected grid loads. As an enhancement to classic grid protection, the grid watch dog (GWD; see also example) monitors

"Plug & automate" as a requirement for viable smart grid implementation

As described previously, the "plug & automate" functionality will be essential for the future implementation of smart grid solutions. At the level of a grid station, for example, this would mean installing an intelligent component in the grid station and connecting it to the communication network. The component would automatically report to the higher-level system, search for any monitoring data in the grid and begin to learn independently to become able to perform a predetermined task, such as voltage control. In principle, this system would only report to operational personnel when it requires basic configurations, if it considers itself ready to start its task, or if errors or faults arise. In fault-free routine operation, however, it would not send any messages to the higher-level systems. This helps to keep personnel expenditure as low as possible and also reduce associated costs.

The scenario described here could be very simple (e.g. a temperature sensor in a transformer station) or highly complex (e. g.state-estimation-based, decentralised load-flow optimisation) depending on the component or system to be integrated. What is clear is that, depending on the scenario, it will only be possible to implement a complete "plug & automate" function to a limited extent. "Low-engineering" approaches will be important in implementation of this function. These are classic approaches that have been optimised so that as many process steps as possible do not need to be performed manually and instead only need to be monitored and approved.



OVERVIEW OF THE APPLICATIONS DEVELOPED AND THEIR INTERACTION FOR THE PURPOSE OF ACTIVE GRID MANAGEMENT

permitted limits in grid operation. These applications all provide supporting functions to ensure that a flexibility operator (FlexOp) can use the "plug & automate" approach as far as possible. FlexOp ensures that the grid, buildings and market representatives can interact as freely as possible by targeting the use of flexibilities. Supplementary economic analyses have also shown the high importance of the synergetic use of the infrastructure required for active grid management. Economically viable operation of smart grids can only be achieved by combining the revenue-generating potential of different applications.

Summary and outlook

These solutions can, to a large extent, be regarded as technically viable, while the use of active grid management will be accelerated, above all, by the requirements placed on grids in future (e.g. fast charging). The only realistic way to achieve economically viable use of smart grid components will be to use the necessary infrastructure to generate synergies by changing grid planning and operation processes. Particular potential for improvement of these technologies can be found in:

- the "plug & automate" functionality of the components used,
- construction of a comprehensive database, and
- adaptation of operating processes to integrate flexibilities.

Use case of the flexibility operator

In the course of ASCR, tests were conducted into the communication between intelligent buildings with an active BEMS and the "responsible", decentralised intelligence in the grid station (iSSN). Thus, a grid-compatible "prosumer" at a point of common coupling (important for load flow evaluation) can be integrated in grid management with little engineering effort. A traffic-light system is used to optimise grid operation. The current traffic-light colour is based on the grid's forecasted status (defined by GSF) and current status (defined by GWD), which are also influenced by supra-regional factors:

GREEN The building uses energy to optimise its economic returns.

AMBER With the help of forecasts (from GSF), future grid issues are identified in advance. Attempts are then made to resolve these issues using available building flexibilities.

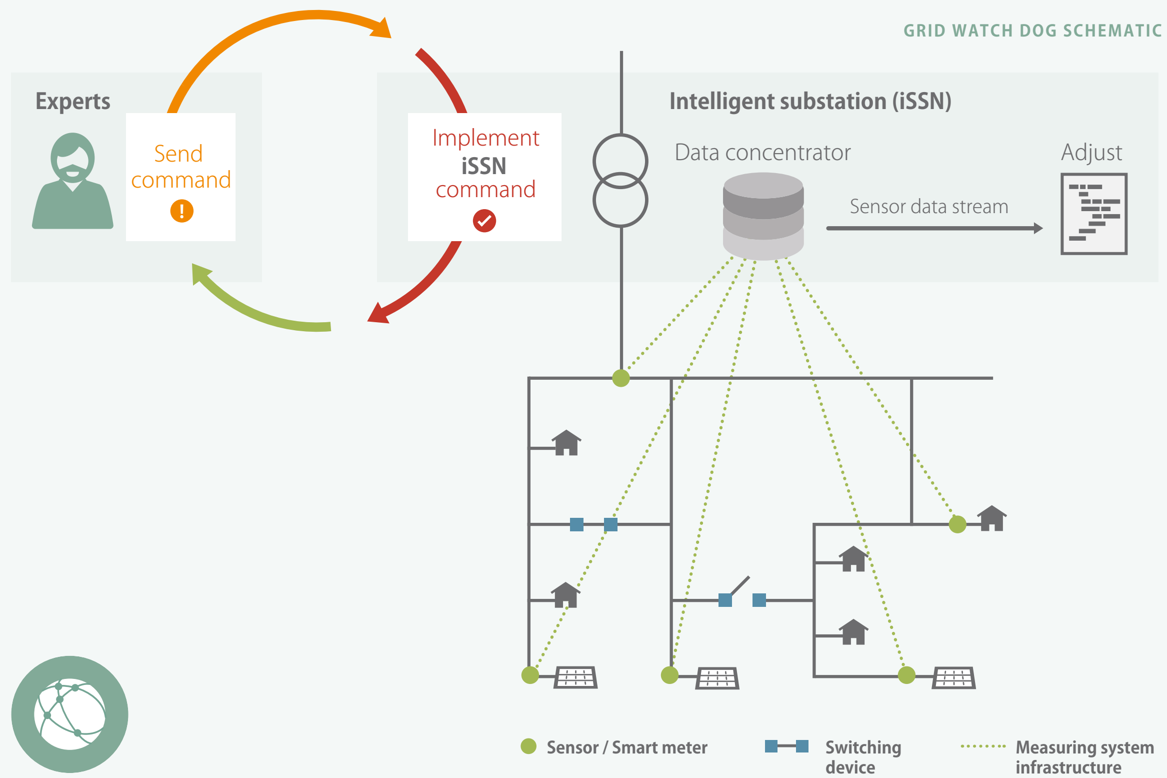
RED The building is requested to reduce or increase its output.

Example application – Grid watch dog

Electrical grid monitoring and control operations are a central aspect of a smart grid, as they facilitate proactive operational management. Grid monitoring and control is performed in the middle-voltage and high-voltage ranges by SCADA (supervisory control and data acquisition) systems. In the low-voltage range, however, SCADA systems are not commonly used. There are several reasons for this. Firstly, a grid operator has a number of low-voltage grids in their grid area.

Integrating all of these grids in a conventional SCADA system would therefore entail significant investment costs for a grid operator. In addition, low-voltage grids are not normally equipped with the ICT infrastructure that a SCADA system would require. The so-called "grid watch dog" application for intelligent transformer and distribution substations (intelligent secondary substation node [iSSN]) has been developed to provide SCADA-like functionality in the low-voltage range. Put simply, iSSNs are nodes in the power grid that will be used in future to control the grid. The iSSNs enable continuous grid monitoring and, should such an incident arise, prevent overloads. The aim of the application is to give grid technicians the ability to implement decentralised monitoring and control rules in a low-voltage grid without having to establish constant central monitoring via a SCADA system.

GRID WATCH DOG SCHEMATIC



5

Insights from the integration of buildings and the smart grid

In the ASCR R&D programme, use cases 1 to 9 investigated what benefits can be generated from the interactions between smart buildings and the distribution grid in the shift towards a sustainable energy system. The building energy management system (BEMS) optimises the use of flexible loads and storage systems (e. g. shifting heat generation by heat pumps to times where local photovoltaic systems generate the most electricity). The BEMS is connected to energy markets via corresponding interfaces in a virtual power plant (VPP) and to the distribution grid via a decentralised grid management system. Performing grid monitoring while simultaneously interacting with the smart building means that the distribution grid can be operated and planned more efficiently and the VPP can participate on energy markets.

Motivation and objectives

As explained in storylines 2, 3, 4 and 6, equipping future buildings with renewable energy generators, energy-storage and heat-storage systems and flexible load systems including sensor and control technology should be considered a basic requirement for using the flexibilities available. If, beyond this, distribution grids are reconfigured as smart grids, grid operators will be able to interact with market partners – not least the electricity customers – and actively manage grid resources, including customers' electric devices (e.g. heat pumps). This will make it possible to get the most out of the infrastructure.

Thus, the ASCR R&D programme provides a unique opportunity to conduct research into how smart energy infrastructure will interact in future at the level of the consumer (building), the low-voltage grid and the user on the basis of measurement data. Storylines 2 and 4 describe the generation systems, consumer components, grid infrastructure components and components of higher-level measurement and control technology that will have to be established and installed in building and grids to achieve this.

This is the source of the R&D programme's aim to gain comprehensive operational experience in integrating buildings and intelligent energy grids and interpreting this for future application in the distribution grids of Wiener Netze and in other development areas of the City of Vienna.

Building operation results

Building load behaviour
New buildings are increasingly fitted with photovoltaic (PV) systems and electrical power storage systems and are increasingly based on decentralised heat supplies realised through the use of electrical energy (e. g. heat pumps). Thus, power consumption (load progression) is more heavily dependent on weather conditions and temperatures. The figure opposite shows an example of the heating demand (heating load behaviour) of the residential building on plot D12 in the winter of 2016/17 compared to the outdoor temperature. Furthermore, building operating modes and occupancy types have a strong influence on their specific load behaviour. For example, ventilation and heating systems are turned down significantly at weekends in the school campus. If such changes in demand (load curves) take full effect, they will create completely new requirements for distribution grid operation and planning. The following sections outline the extent to which these requirements can be influenced by building optimisation measures and operational strategies for buildings' participation in energy markets.[1]

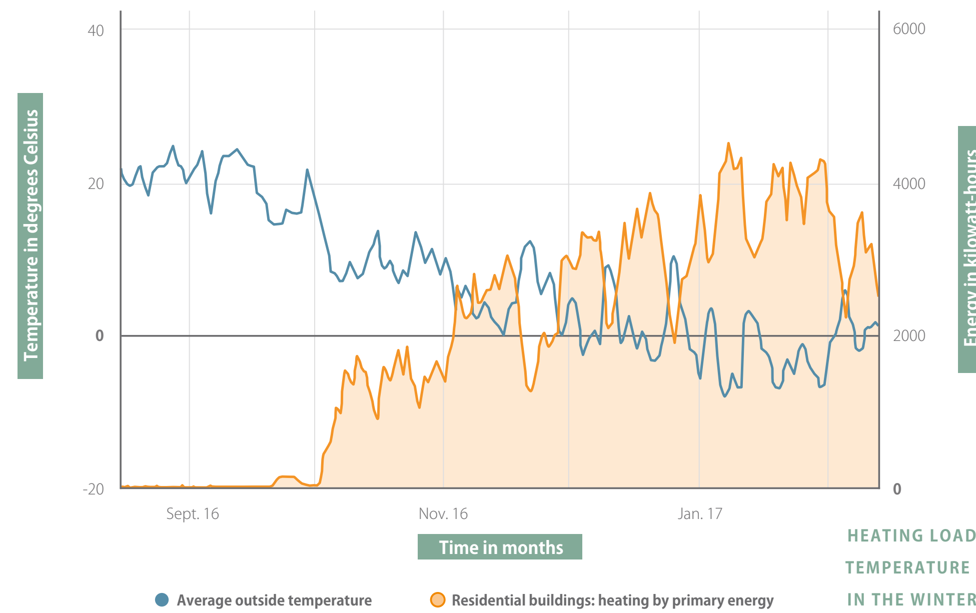
Building energy management system – BEMS
A comprehensive building automation system (BAS) is used to control and regulate the components installed in buildings. While established systems are already in use at the field level and at automation level to ensure normal operation and security functions, this was taken as the basis for developing a building energy management system (BEMS). The BEMS uses the flexibilities available in a building, such as electrical and thermal storage systems as well as energy conversion components (heat pumps, cartridge heaters, etc.), to optimise building operation on the basis of different parameters. It differentiates between the following use cases:

1. Minimal operating costs: The building optimises its electricity purchase and feed-in to the grid based on price forecasts for the next 24 hours. (Note: This strategy is addressed in further detail in storyline 2.)

2. Optimal energy purchase: The price forecasts for the next day show when electricity is expected to be particular cheap and when it will be particularly expensive. Based on this, a plan is created outlining how much electricity will be consumed and when over the course of the day. Electricity is purchased accordingly on the day-ahead market, on which electricity is traded for the following day.

3. Offering and providing flexibility: The building plans its energy consumption so that its flexibility can be commercialised, e.g. on the control energy market. For this purpose, in addition to energy purchase costs, the building also takes into account price forecasts for positive and negative flexibility availability. (Note: This is addressed in further detail in storyline 3.)

1 At this point, it would be useful to mention that storylines 2, 3 and 6 explore in detail opportunities that building optimisation systems could open up (e.g. optimising internal consumption of self-generated energy, participating in control energy markets or using energy storage systems).

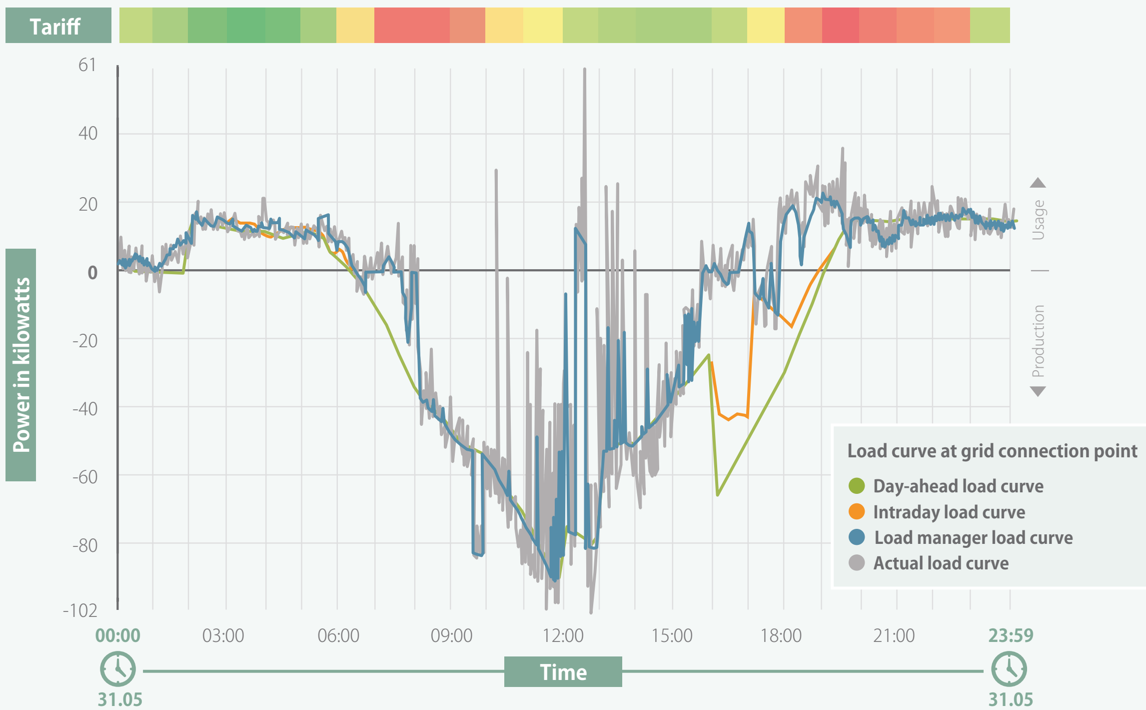


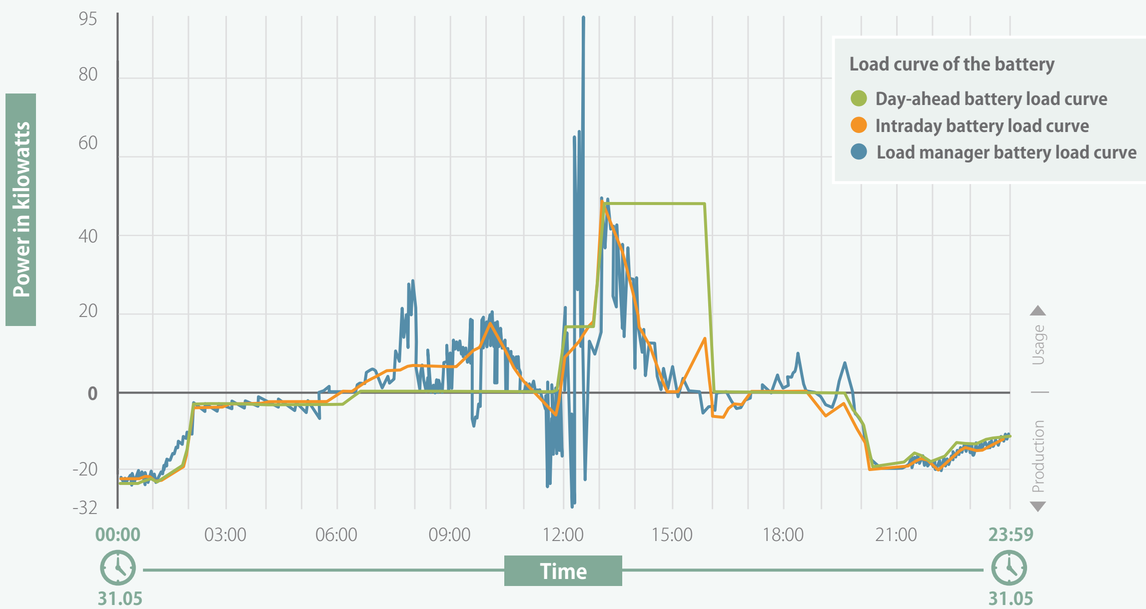
HEATING LOAD BEHAVIOUR AND OUTSIDE TEMPERATURE FOR RESIDENTIAL BUILDING IN THE WINTER OF 2016/17

A four-level control architecture was selected for the BEMS to cover all of these use cases. For a better description of the architecture, see storyline 2.

Building interfaces
As an active participant in a future energy system, an intelligent building will cooperate with other external entities (including other buildings, the power grid and the electricity market). Although some approaches to standardising data transmission already exist, a widely accepted and comprehensive standard has not yet been established. That is why corresponding protocols and data models were implemented in connection with these standardisation activities.

XMPP (extensible messaging and presence protocol) was selected as the transmission protocol to establish a connection to the energy market (via a VPP, cf. storyline 3) and to the intelligent transformer station. Proprietary data models were used – the latter being easier to replace if standardisation committees can come to an agreement. XMPP is used to transmit load forecasts and energy tariffs; the protocol facilitates the trading of flexibilities between buildings and the energy market and distribution grid. In addition, XMPP is used to transmit emergency signals from the distribution grid to trigger immediate load changes (see also the section "Results for grid operation"). Communication processes are structured in a way that allows participating entities (buildings, grid, market) to trade flexibilities depending on their respective action strategies. Technical and regulatory frame-





LOAD PROGRESSION AT POINT OF COMMON COUPLING (ABOVE) AND ENERGY STORAGE SYSTEM LEVEL (BELOW) FOR A REPRESENTATIVE DAY

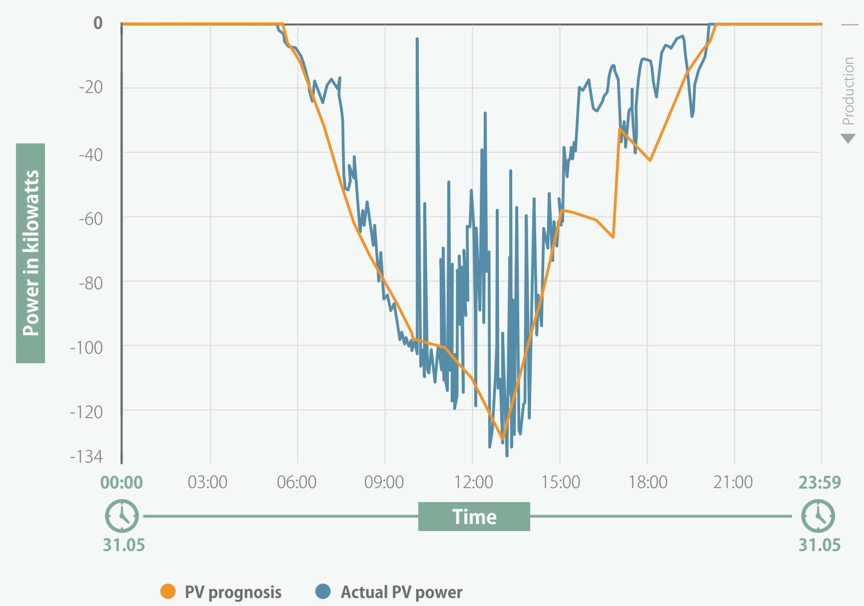
Examples of results

The figures show the results for fully automated operation of the student dormitory by the BEMS (in each case as output in watts over the course of a day), with the underlying energy tariffs indicated by the colours (red = high prices, green = low prices). They demonstrate use case 2 with dynamic pricing. The tariff is determined by the prices on electricity exchanges, which change every hour. In this manner, a cost-optimised load profile for the next day (day-ahead load profile in the figure above) is produced at the point of common coupling.

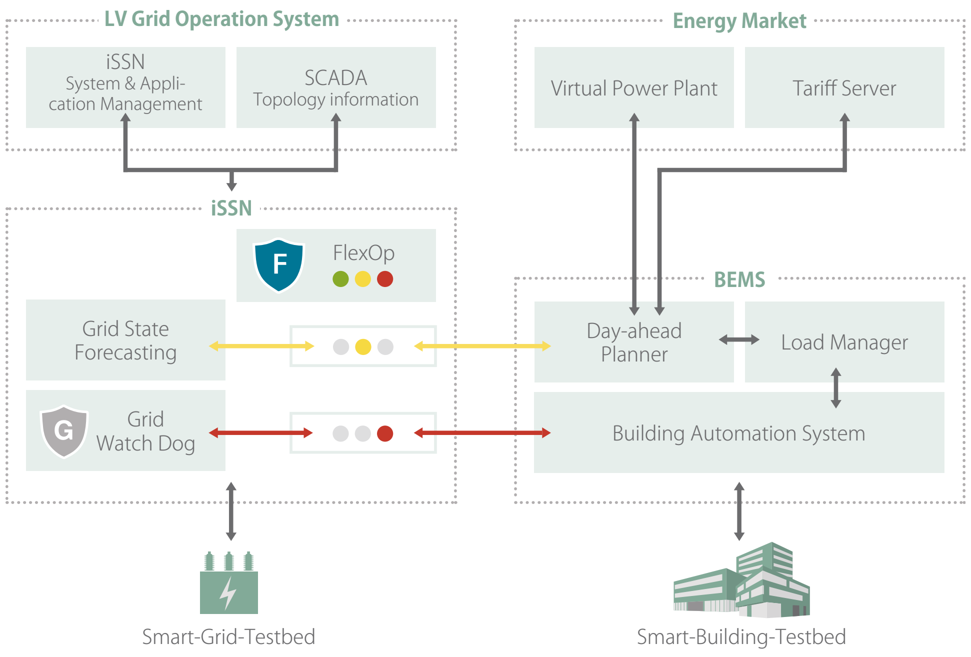
In this use case, the BEMS must follow the profile forecast the day before at the point of common coupling in operation as far as possible, in spite of flawed forecasts, faults and inaccuracies in the model. In order account for these expected fluctuations, the intraday replanner “re-optimises” operation on an hourly basis. One level further down, the load manager can compensate for short-term fluctuations at one-minute intervals.

In the figure on the left, the load progression at the point of common coupling, which has been adjusted accordingly (intraday load progression), balances out an over-optimistic forecast for power generation by the PV systems. Operation of the energy storage system is also adjusted accordingly (day-ahead vs. intraday storage load progression). It is clear that the measured values at both the point of common coupling (actual load progression) and in relation to the charge level of the battery (actual storage load progression) mostly correspond to those calculated by the intraday replanner in cyclical corrective planning.

In areas where deviations between the two profiles are visible, the actual PV system output differed significantly from the forecast PV system output (see following figure). Due to the low cost of electricity, these deviations were offset by power drawn from the public grid, which had not been forecast in the day-ahead planning. Moreover, the figure below displays the availability of flexibilities, as described in use case 3. Here, positive control capacity is provided for a period of 15 minutes, followed by negative capacity for the rest of the day (for further details, see storyline 3).



PV SYSTEM OUTPUT PERFORMANCE VS. ACTUAL RECORDED OUTPUT



OVERVIEW OF RELEVANT APPLICATIONS AND COMPONENTS IN BUILDING-GRID INTERACTIONS

work conditions are also taken into account. The approach adopted in this work has been discussed in the past in the responsible standardisation committees (e.g. IEC TC57 WG21).

The BEMS relies on weather forecasts to make anticipatory optimisations. These forecast are primarily required to predict the volatile generation of energy by PV systems. They also enable energy consumption to be predicted more precisely, in particular through the use of temperature forecasts. There are no standardised interfaces for this type of data. Depending on the provider, a REST API (representational state transfer for application programming interface) is usually made available.

In any case, for optimal building operation, an interface is needed to retrieve information on dynamic time-variable energy tariffs. This interface can either be designed to function independently or integrated in the interface to the virtual power plant. When implemented as an independent interface, it is usually reliant on a specific energy provider. The provider usually provides a REST API which can then be used to retrieve current tariffs for that day.

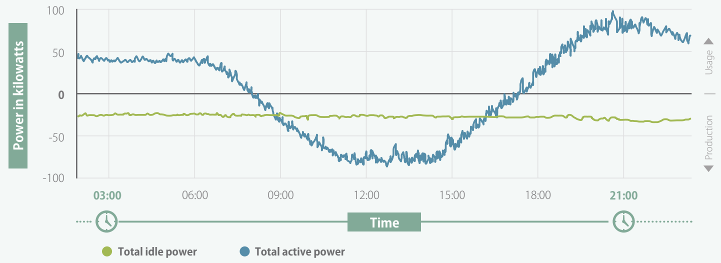
Results of grid operation

Grid monitoring using data from the distribution grid

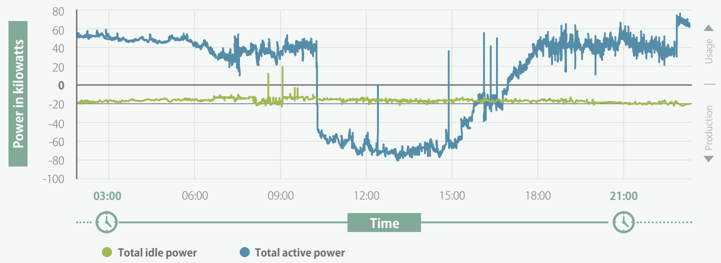
As described in previous sections, smart buildings can interact with a virtual power plant (VPP) via an intelligent BEMS and be bundled together with other potential flexibility providers to participate in existing markets – as well as in potential future markets. Examples of existing markets include spot markets and control energy markets. The reactive power market[2] is one key example of a potential

2 Grid operators' processes to procure the required reactive power are not particularly transparent at this time. These processes are usually controlled by contracts with generation plants or through bilateral agreements between grid operators (e.g. between distribution grid and transmission system operators). In future, decentralised systems, emergency standby power systems and self-generation systems will make a contribution at lower grid levels and, in doing so, reduce the load on transmission systems and higher grid levels. At present, however, no such market exists.

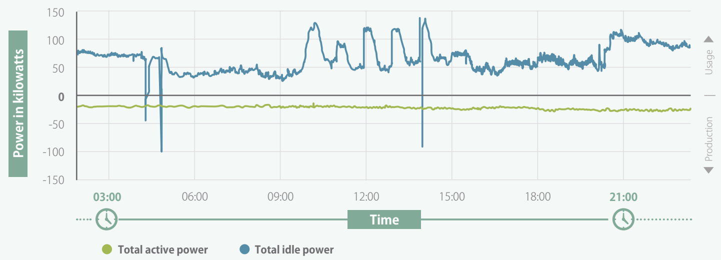
Examples of observed consumption patterns



ACTUAL POWER WITH CLEAR ENERGETIC RECOVERY DUE TO PV SYSTEM WITH BEMS DEACTIVATED



EFFECTIVE POWER WITH STANDARD BATTERY CONTROL TO OPTIMISE INTERNAL CONSUMPTION



EFFECTIVE POWER PROGRESSION WITH ACTIVE BEMS WITH CONTROLLED BATTERY STORAGE SYSTEM AND ECONOMIC OPTIMISATION BASED ON FLEXIBLE ENERGY TARIFFS

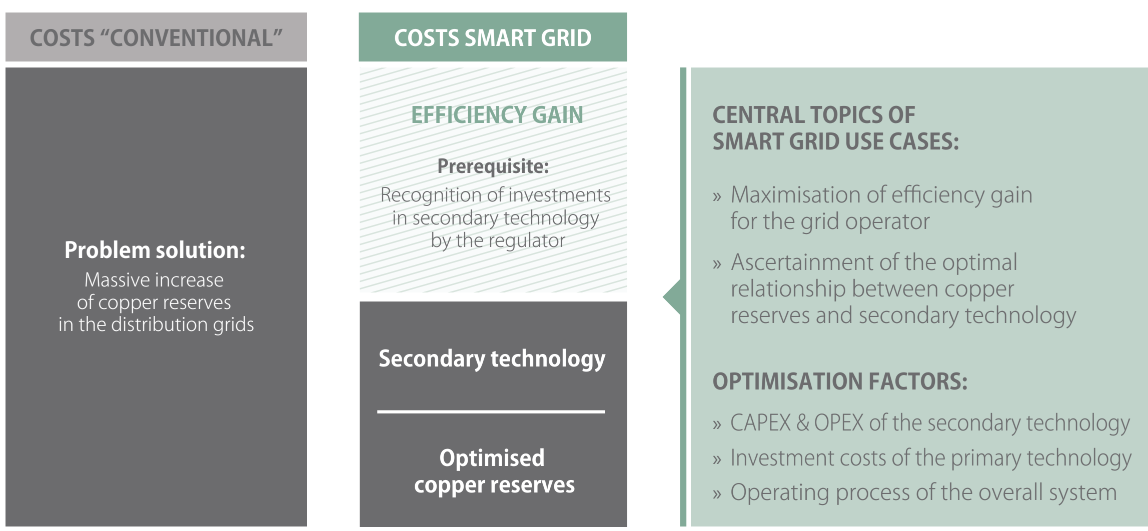
The individual effective power progression charts make clear that smart buildings' participation in various energy markets is challenging previous assumptions regarding load simultaneity. This means that, as mentioned previously, smart buildings and electric systems in smart buildings could soon be aggregated into virtual power plants. The combined electrical output of buildings and/or installations, however, could be so high that they overload a low-voltage or even medium-voltage grid. Potential grid overloads would therefore need to be forecast and the information communicated to intelligent systems within the distribution gird (either directly or through a VPP). This could be facilitated by optimising the building's communication technology – as in this case – so that it can better exchange information and then react quickly to find a solution to a potential grid problem.

future market. However, current VPPs aggregate existing flexibility independent of the surrounding distribution grid infrastructure. From the perspective of grid operation, initial measurement values show that smart buildings are significantly transforming consumption patterns.

Grid operation in cases of high utilisation – using a flexibility operator

Monitoring within the grid and interaction with buildings allow the infrastructure to be used closer to its physical limits, which improves the use of the capacity of the installed components. Nevertheless, if smart buildings are to have broadly unlimited access to various markets in future, this poses the challenge of how it can be achieved without having to significantly reinforce power grids. Numerous external actors in the distribution grid will have to interact in a simple and secure manner. However, the commissioning and ongoing operation of such a system must not incur significant personnel expenditure, as this would lead to high costs. If these costs were attributed to smart buildings, the economic viability of their free participation in the energy markets would be called into question. On the other hand, it would be equally unacceptable for the costs incurred by individual smart buildings to be passed on to others in the form of grid tariffs. The use of self-configuring systems today appears to be absolutely crucial to the future use of optimised secondary technology to achieve maximum efficiency gains (cf. also the figure below).
Therefore, based on the traffic-light model (such as that of the Smart Grid Austria technology platform), a multi-stage system (flexibility operator – FlexOp for short) was also defined in ASCR research activities to provide upstream protection against grid overloads. This system is divided into the following areas:

- Red area – "MUST": The grid operator can specify a load profile change for the BEMS directly by sending a corresponding binding notification. The BEMS then makes this change as soon as possible. The decision of which flexibility to use in the building remains with the BEMS. This ensures that the grid can operate securely because key system parameters are taken into account. Still, the most fundamental customer requirements – such as the need for a sufficient heating supply during the cold season – can also be covered as far as possible, even in critical situations. As an extension to classic grid protection, the grid watch dog (cf. also storyline 4) monitors permissible limits and generates notifications or messages (events) in the event that any limits are exceeded. In the event that limits are exceeded, the "RED" submodule of the FlexOp can send specific change specifications to the BEMS of supporting smart buildings.
- Amber area – "CAN": Forecasts enable the participants to identify impending overloads and to offer corresponding flexibility reserves. The goal is to find a market-based solution to the problem. In specific terms, grid state forecasting (GSF; cf. storyline 4) creates an intraday forecast for expected grid loads. On the basis of the GSF, the FlexOp ensures that the grid, buildings and market representatives can interact as freely as possible, with targeted use of flexibilities. This makes it possible to avoid restrictions in grid usage to the greatest possible extent.
- Green area – No limitation on market participation. The BEMS uses the storage capacities available in the building to achieve an optimal load profile for the building.



SUMMARY OF THE EFFICIENCY GAINS ACHIEVED FROM SMART GRID OPERATION AND PLANNING

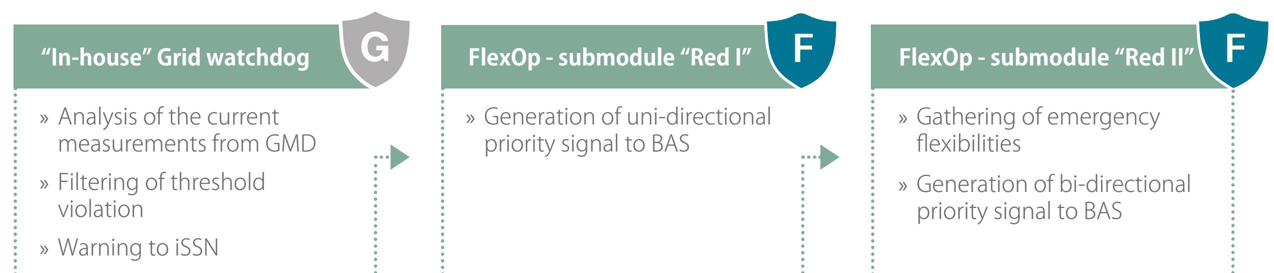
Active grid management through building flexibility

Grid operators will need a series of applications to facilitate interactions with buildings. In addition to the aforementioned software programs and applications, such as the grid watch dog, a series of other subordinate background functions were developed in the course of the ASCR. These should facilitate an operating method that is automated as far as possible in the sense of "plug & automate" (for more information, cf. storyline 4).

It is assumed that the iSSN (intelligent secondary substation node), which serves as the basis for active grid management, and all BEMSs in a given area will be able to communicate with one other over a shared XMPP server. Basic functionalities for grid management were also developed according to the traffic-light model:

Basic functionality – "RED"

As an extension to classic grid protection, the grid watch dog monitors the permissible voltage and power limits in the related grid area. It uses the measurement values recorded by the sensors installed in the test bed – referred to as the GMD – and generates events when the limits are violated. The "RED" submodule of the FlexOp then has the following task: It transmits the change specifications of the supporting smart buildings to the BEMS. In this, it relies on the events and other external information, such as the structure of the grid (static grid topology) from the subordinate low-voltage grid operating system (LVGOS). The LVGOS is the operating system for the low-voltage grid to which smart buildings are connected. The entire monitoring functionality can therefore be divided into three configuration levels (see figure below). Level 1 is the grid watch dog itself. This program analyses the



CONFIGURATION LEVELS IN THE "RED" PHASE

decentralised measurement values and monitors critical exceedance of limits values, whereby not every short-term violation of a limit value needs to result issuance of a warning, nor should it. The generated events provide information and can, for example, be issued as warnings via a dashboard. It would also be conceivable to have an automatically generated message sent to a responsible operational technician, at which point they can then initiate the necessary steps (e.g. switch-overs in the grid).

In the "Red I" variant, unidirectional information represents an imperative demand for the BEMS to make real-time load adjustments. Different variants are conceivable in this regard (target values, limits, adjustment of P/Q, etc.). The priority signal is unidirectional. It indicates that appropriate arrangements must be made to ensure that no oscillations arise in the system.

In the "Red II" variant, there is a bidirectional exchange of information between the BEMS and iSSN. The adjustment of available potential for load shedding/increases takes place in real time (within one minute). Targeted and selected load shedding/increase requests are made to resolve problems. Different variants are also conceivable (target values, limits, adjustment of P/Q, etc.).

Basic functionality – "AMBER"

The FlexOp uses the aforementioned "plug & automate" functionalities to solve the problem, which are based on the traffic-light model. The grid state forecasting module produces appropriate grid load forecasts. It uses the consumption forecasts (day-ahead profiles) issued by smart buildings. These forecasts enable the participants to identify impending overloads and to offer corresponding flexibility reserves, as described in the section "Results for building operation". This means that the building that is able to solve an impending problem with the most economically/technically effective means is rewarded for its contribution to grid optimisation. Whether the requested and reserved flexibility is also required in fact depends on the probability of the forecast overload actually occurring. Similar to the red area, two scenarios have been defined for the amber area.

In the "Amber I" variant, information on planned timetables is retrieved from the BEMS. With the help of the grid state forecasting module, the threat of future overloads can be identified (+6 hours into the future). Then, a unidirectional message is send to the iSSN (archive) and/or to the BEMS regarding the threat of threshold breaches in future. This variant could also be considered as an open-loop application of the FlexOp. It can be used to determine how often a threshold breach can actually be forecast and how often breaches that are forecast then indeed occur. This variant provides a basis for the economic analyses that are performed. Thus, the potential costs of implementing a FlexOp in the test bed (depending on the grid relief achieved) are between €50,000 and €150,000 (cash values).

The "Amber II" variant, which underpins the descriptions in the section "Results for building operation", represents an extension for actual grid-building interactions. As described previously, the FlexOp identifies the threat of future overloads. The FlexOp "buys" available flexibilities corresponding to the flexi-timetable information sent by the active BEMSs in the grid. Any remaining free flexibilities in the building are used first. If these are not sufficient, the flexibilities already reserved by other actors (e.g. virtual power plants) are drawn on to solve the impending problem in the grid. Experience gained to date indicates that the risk of availabilities actually overlapping is low.

Summary and outlook

The ASCR's research activities demonstrate a design for a building optimisation system that has been implemented in real life. This system actively controls the "prosumer" components based on forecast methods through individually adjustable operating modes. The cascading structure (day-ahead planning, intraday replanning, load management and base controller) makes it possible to ensure reliable operation even in the case of forecasting errors or short-term events. It is, furthermore, possible to realise different operating conditions and use cases. In addition, the optimisation system builds on the existing building management system. During these research activities, the system was successfully implemented, including retrieving flexibilities. A smart building is connected to all relevant external stakeholders (grid, market, data) via the interfaces that were discussed in the standardisation committees.

Grid operation with self-optimised "prosumers" (i.e. smart buildings) requires a flexibility operator to fulfil the two following tasks. In the event of acute limit exceedance reported as an event by the grid watch dog module, change requirements are sent to the grid-supporting smart buildings, which then immediately implement these specifications (i. e. the solution to a problem in the grid's Red area).

The grid state forecasting module then provides information on more short-term grid status. Impending grid problems (amber area) can be resolved by retrieving individual, usually free flexibilities. This active grid management approach was implemented in prototypical form in ASCR.

The aims of future research activities should include, first, fully implementing the building optimisation system with connections to other energy market segments. New topics such as mobility and sector coupling (e.g. electricity, heat, gas) should also be analysed.

In any case, the results achieved so far are prototypical realisations of internal building optimisation systems that can be used in future by building contractors and building operators. This would make it possible to certify entire buildings as "smart grid-ready" and – subject to corresponding implementation of a flexibility operator with "plug & automate" functionalities – then actively integrate them in future distribution grid operation and planning. This would make it possible to prevent further peak loads in operation and, in doing so, avoid expensive grid expansion measures.

6

Shared use of energy storage systems

The ASCR R&D Programme has the long-term goal of implementing a “multi-use energy storage system”. This means that, while the focus of its research activities is on how energy storage systems can be used for grid-supportive purposes, it also gives consideration to further areas of application for energy storage systems (primarily on the basis of simulations). These grid-supportive purposes primarily relate to active and reactive power management and phase balancing. Potential market-friendly operational strategies provide other uses for energy storage systems, e.g. on the intraday market or to optimise private consumption.

Motivation and objectives

As decentralised energy production becomes increasingly common and the number of "new" consumers with high simultaneities (e.g. e-mobility) to be integrated in the supply network continues to rise, so does the complexity of the system as a whole. Consequently, a strategic adjustment must be made in terms of grid operation and planning. In addition, asymmetrical load distribution in the distribution grid causes phase asymmetries that may not exceed legal limits. Therefore, these challenges are examined in further detail under real conditions in the ASCR test bed.

Grid expansion would be one solution to these challenges, but would also entail significant costs. The R&D programme examines a smart grid concept as an alternative to this: it seeks to integrate energy storage systems in the distribution grid in order to resolve the aforementioned challenges. At the same time, it attempts to make a positive contribution to existing market requirements (e.g. shifting energy surpluses at times when little energy is available) in the course of the energy transition. This also includes localised coupling of energy generated and stored in decentralised systems – which could then be consumed locally when later needed.

The research objectives of storyline 6 can therefore be summarised in simulations, laboratory operation and consideration of moving towards potential cross-stakeholder use (multi-use) and a technical, economic and legal analysis. These topics are being investigated on the basis of the actual implementation of energy storage systems in the smart transformer stations in Seestadt.

Results

Five energy storage systems were installed in the smart transformer stations in the smart grid test bed. An energy storage system comprises a lithium iron phosphate battery – with 100 kW output and 120 kWh capacity that is executive with a three-phase (4-wire) B6-bridge inverter.

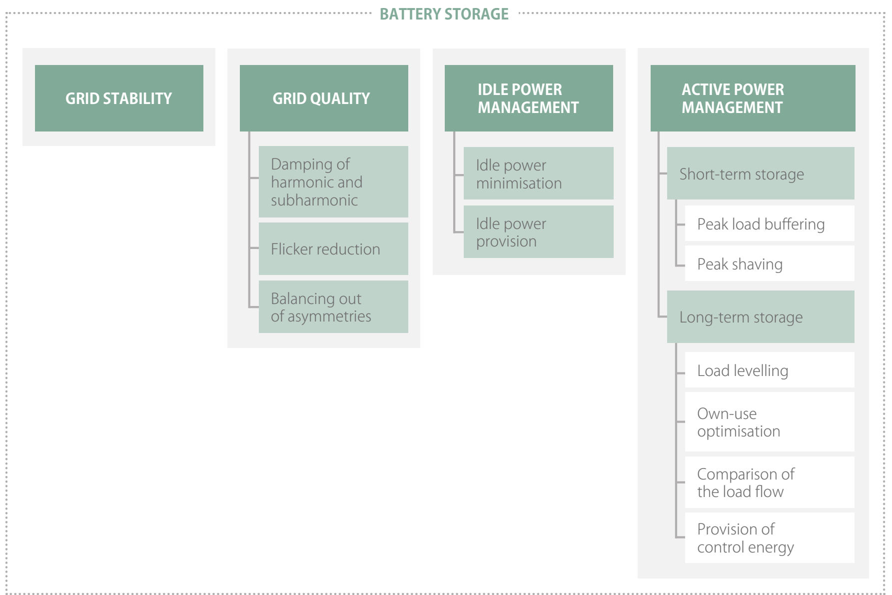
Energy storage systems represent a new operating resource for distribution grid operators. They are active systems that that facilitate flexible use and dynamic control. Field operation of such systems in the smart transformer stations in Seestadt has made it possible to gather initial empirical values. The results show that there are numerous potential uses to provide grid services relating to grid stability and grid quality. Furthermore, simulations help analyses of grid losses and support efforts to determine and map out the potential of free energy storage capacities for the market.

In the course of the research, grid system services were identified, classified and prioritised (cf. figure below), which made it possible to determine the diverse requirements of the actual installed energy storage system.

Experiences in field testing
Field operations show that installing a storage system involves a time-consuming commissioning process. On the one hand, energy storage systems are resources with many degrees of freedom; on the other hand, however, they increase the level of complexity. In future, therefore, there is a need for solutions that support "plug & automate" functionalities – that is to say, solutions that enable integration in existing systems as easily as possible. This would then require an increasingly multi-layered IT architecture. In addition, security requirements in general would be increased by the fact that new communication connections would be established in levels of the grid that previously had almost no automation, which would ultimately also create potential attack vectors. At the same time, the system would require additional accesses, such as the potential for the manufacturer to access it remotely to apply updates and perform maintenance.

Currently, energy storage systems are not yet fully able to meet the desired technical requirements of distribution grid operators because their manufacturers also do not have any experience of these specific use cases (i.e. combining an inverter with a battery) envisaged by distribution grid operators. Therefore, a high level of manual engineering is required today. So this activity is also an important part of industrial research (laboratory research). Prototypical energy storage systems with operating modes designed for distribution grid operators are already available, as the FACDS research project has shown. However, at present, there are no market-ready energy storage system solutions available to meet the multi-functional requirements of distribution grid operators. From the research programme's perspective, there is, as already mentioned, a need for a high level of manual engineering. The field tests show the following:

Phase symmetrisation: Asymmetries in the distribution grid are homogenised through phase-selective



CLASSIFICATION OF GRID SYSTEM SERVICES PROVIDED BY ENERGY STORAGE SYSTEMS inverter operation. Balancing the load across all phases makes it possible to mobilise the available grid reserves.

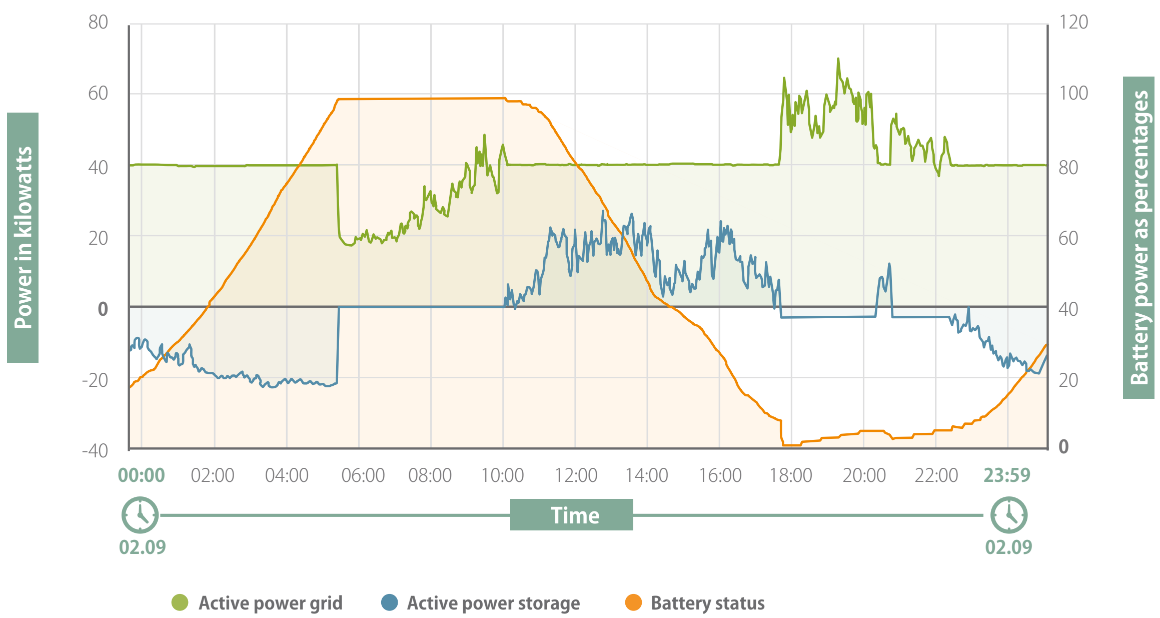
Reactive power management: In addition to so-called active power, reactive power also occurs in alternating current systems. This "swings" between the power grid and the consumer and, while it does not do any electrical work, it does cause losses. It should therefore be kept as low as possible. Electrical storage systems can help to minimise reactive power and ensure a sufficient provision of reactive power.

Peak shaving and control: Peak shaving means slightly reducing the energy purchased from the grid or fed into the grid. This allows the distribution grid to operate more effectively and adhere to technical system limits (cf. also following figure).

Reducing the load on resources can have positive effects on the deteriorating of equipment. This makes it possible to delay investments in expanding a distribution grid, or to structure them more efficiently.

Simulations

Storage simulations provide valuable input for an economic analysis of multi-use of energy storage systems: time series of performance or energy values can be used for market-based business models and for a commercial analysis. This input is provided through the storage and usage models developed in the project. The different models providing grid system services (e.g. phase symmetrisation or peak shaving) thus differ from the following market-based models. To obtain an initial estimate for hybrid use, the individual grid-based and market-based services



PEAK LOADS ARE CAPPED BY THE CONTROL SYSTEM IN THE TRANSFORMER STATION. THIS MAKES IT POSSIBLE TO SPREAD THE LOAD MORE EVENLY ACROSS RESOURCES. THE SETPOINT VALUE IS DEFINED AS 45 KW +5/-10 KW (AS OF 2/9/2018)

were examined using simulations. It was intially hypothesised that phase symmetrisation alone could reduce overall grid losses. If the internal losses of energy storage systems are not taken into account, it can be seen that symmetrisation has a positive effect on grid losses.

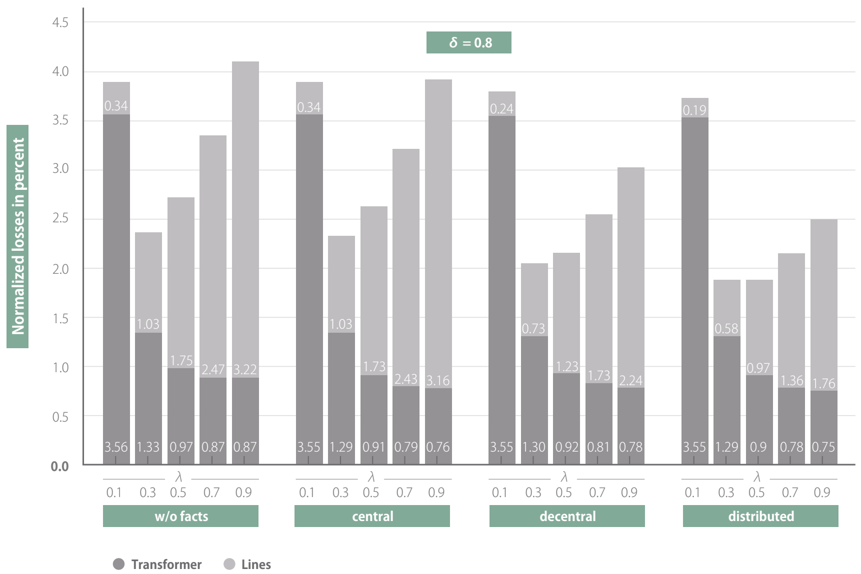
In the next step, the losses exceeding the inverter's efficiency factor were taken into account in the previous results.

The system losses examined in the research programme – that is to say, the losses from the battery and the inverter – are only dependent on the line load (Λ cf. figures on the next page) to a minimal extent. A significant difference can be identified between different asymmetry levels (δ cf. figures on the next page). The analysis shows that the "central" installation scenario (i.e. central energy storage system in transformer stations) has the highest losses, followed by the "decentral" (individual energy storage system, e.g. at the end of a line) and the "distributed" (small-scale storage systems distributed at customers' grid node points). The simulations also show that losses can only be reduced in the "distributed" installation scenario. However, even in this scenario, this only applies in the case of high line capacity use and a high degree of asymmetry.

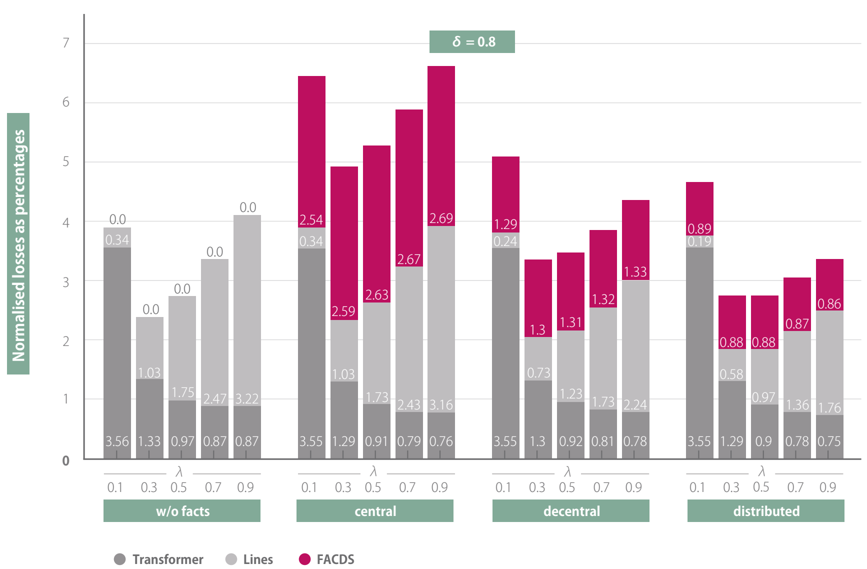
It can therefore be seen that phase symmetrisation for the purpose of loss minimisation and exclusively using the inverter for symmetrisation is not effective and does not produce any notable added value. Consequently, symmetrisation should not be used for loss minimisation purposes; it should only be used in the case of high asymmetries – for example, to comply with operating limits of individual phases. This ensures that the asymmetries do not impair the structural N-1 security of the urban low-voltage distribution grid. This means that, even if important components were to fail, the grid will continue to operate reliably.

Phase symmetrisation should therefore not be considered an exclusive function of the energy storage system, but rather as an add-on to another use or to a primary use. For example, placing a higher load on the inverter valve and providing amounts of energy on the market makes it possible

The envisaged multi-use of the energy storage systems examined here will open up new business models. However, it is still important to analyse this issue in detail from business and economic perspectives. Nevertheless, it is already clear that legal and regulatory factors are currently complicating the implementation of shared-use energy storage systems. New framework conditions should change this so that energy storage systems can be used effectively as a decisive, key to implementation of the energy transition.



GRID LOSSES (NOT INCLUDING STORAGE LOSSES) DEPENDING ON INSTALLATION SCENARIOS AND LINE CAPACITY USE FOR A MAXIMUM POWER SPREAD/DEGREE OF ASYMMETRY OF Δ = 80 % (HIGH ASYMMETRY)



GRID LOSSES (INCLUDING STORAGE LOSSES) DEPENDING ON INSTALLATION SCENARIOS AND LINE CAPACITY USE FOR A MAXIMUM POWER SPREAD/DEGREE OF ASYMMETRY OF Δ = 80 % (HIGH ASYMMETRY)

to exploit synergies and combine them with symmetrisation. Furthermore, placing a higher load on the valves makes it possible to achieve significantly higher overall efficiency (up to 98 %).

For the "reactive power management" operating strategy, experience shows that performance factor specification (cos(phi)) works well in technical terms. The reactive power can accordingly be provided in higher levels of the grid. Long-term experience will make it possible to quantify the level of relief this provides.

In relation to the "peak shaving" strategy, it was identified that a specified maximum power limit can be adhered to both in simulations and in reality. However, in contrast to the simulations, full power is not used in reality, but the storage that has reduced charging capacity is instead recharged after a specified time period.

Shared use of energy storage systems

Energy storage systems are commonly seen as a key to implementation of the energy transition. Electro-chemical energy storages systems, such as battery storage devices, are currently usually operated by actors who hope to gain economic benefits from operating their energy storage systems in addition to securing the supply of critical (grid) infrastructure. For example, domestic storage systems make it possible to increase their private energy consumption rate, e.g. from photovoltaic systems, and to benefit financially from doing so. These observations also apply to larger-scale energy storage systems such as those integrated in buildings in the smart building test bed (student dormitory). One aspect all applications have in common is that the private use of electro-chemical storage devices is not economically viable at present due to the current price structure. The ASCR R&D programme is examining whether the shared use of energy storage systems is possible when access is given to numerous actors/stakeholders. On the one hand, this could be used by the operators of decentralised systems to optimise private consumption rates. On the other hand, energy suppliers could store energy during periods when wholesale prices are low and supply this to their customers at more affordable prices at times when prices are higher. In parallel to this, distribution grid operators can also use energy storage systems to provide grid services. In this context, the storage and inverter capacity should be considered a priority in order to support the grid. Only the remaining potential should be used for economic optimisation. The ongoing field test will highlight possibilities.

Legal and regulatory assessment

First, legal and regulatory assessments have been performed regarding the current status. On the other hand, however, investigations are underway to examine a potential future development, namely the legal classification of energy storage systems in the energy industry. This is looking at topics relating to the rights of grid operators' to establish and operate storage systems.

The evaluations of the legal situation of storage systems shows that, based on the classification of storage devices in the existing market system under electricity legislation, energy storage systems – like pumped-storage power plants and power-to-gas plants – are regarded as end-consumers and take-out systems when storing energy, and as generators and feed-in systems when energy is withdrawn from them. They therefore assume a dual role to which special tariff regulations currently apply (primarily for pumped-storage power plants). In the investigation into the entitlement to establish and operate a storage system, it should be noted that, at present, and unlike provisions concerning gas storage system operation, there are no unbundling requirements in place for the operation of an energy storage system either at the national level in Austria or at the EU level. Therefore, in the context of the previously described classification of an energy storage system, the question arises of who is actually permitted to establish and operate such a system and whether a grid operator would also be able to do so based on the provisions of unbundling legislation.

Commercial and economic assessment

The energy storage system installed in the smart grid test bed is subject to a variety of different operating

strategies. Returns vary according to differing target functions (e.g. to minimise grid utilisation) and, subsequently, affect the economic viability of the system. Owing to their high procurement costs, investments in the energy system are often subject to long review periods. In addition, long-term forecasts for energy prices and interest rates on capital are difficult to produce and can be imprecise. Therefore, in the course of the ASCR R&D programme, a business model was developed that facilitates both a static and a dynamic assessment of future price scenarios and capital market developments. This was achieved with the help of Monte Carlo simulations in which all variable parameter combinations were simulated for each factor variation. This allows us to make the most wide-ranging and informed statement possible regarding the planned investment project. The basis of this model is the dynamic capital value method. This makes it possible to integrate dynamic changes on both the output and input sides. Thus, it maps out the estimated amortisation period, the internal interest rate and the electricity production costs.

From the perspective of welfare economics, it raises the question of what costs and benefits will be passed on to society and the national economy as a result of potential measures to integrate decentralised, renewable energy generation systems. To comment on the benefits that using energy storage systems to support power grids could bring to the national economy, distribution effects, trade balance effects, external effects and competition effects (technological leadership) also need to be discussed. In addition, the regional economic importance of central strategies for the grid-supportive use of energy storage systems also needs to be quantified in comparison to conventional grid expansion. Ongoing research will show relevant results.

Summary and outlook

The solutions for grid-supportive energy systems that have been developed in ASCR can be considered technically implementable. At the same time, however, the achievable grid-supporting effects must always be considered in relation to the costs involved and potential alternative and conventional solutions (e.g. grid expansion). This will be quantified in greater detail in future research activities. In any case, the following points are foreseeable at present:

- Grid upkeep and contributions to system stability are duties of distribution system operators and are in the interests of all customers. Grid stability, grid quality and supply stability must also continue to be ensured in future. Short-term peak loads will occur more often and become more volatile, which represents an additional strain on the grid. The fluctuating feed-in of energy and customers' changing power purchasing and feed-in behaviour mean that new solutions are required to provide flexibility. Integrating energy storage systems in the grid infrastructure in future therefore represents a potential instrument for distribution grid operators to obtain grid services as well as a potential source of flexibility.

- From a business perspective, facilitating cross-stakeholder use of storage capacities is set to have a decisive key role in the foreseeable future. At present, there is hardly any experience of the shared use and process coordination of storage capacity either between grid operators or between grid operators, energy suppliers and end customers. Further analysis must be conducted and potential scenarios defined. Specific recommendations can then be derived for the future creation of a regulatory framework (primarily in relation to energy storage systems distributed across wide areas).

- Power electronics and associated system integration, information and communication technologies (ICT) and automation are key technologies for the future development of society. Applications without power electronics are almost unthinkable in the field of electricity grids. So, detailed requirements must be imposed on hardware and software for power electronics as well as battery management. In doing so, developing solutions that are as simple and self-configuring as possible ("plug & automate") will be crucial.

7

Big data – uses and added value from the world of data

The previous storylines described the data sources that have been used for management and optimisation of buildings and power grids. The present storyline discusses the concomitant analysis and interpretation of data in the research areas of buildings, users and grids. The result is a number of data evaluation and interpretation options that, in addition to optimising the operation and costs of power grids of buildings, can also serve as a basis for decision-making by regional stakeholders (e. g. urban designers).

Motivation and objectives

Around 1.5 million measurements are recorded in the ASCR test beds every day. The aim of the research programme is to use intelligent analysis of this data to gain new insights for the energy supply of the future.

After 111 households gave their express consent, data was collected to achieve this research objective. Sensors measure the temperature, humidity and CO_2 content of the air and record consumption figures for water, heat and electricity in each building and apartment. Heat pumps, solar systems and energy storage systems also continuously communicate their operating status (cf. also storylines 2 and 3). Weather sensors provide information on the current temperature and sunshine. More than 100 monitoring devices in the low-voltage distribution grid and transformer stations simultaneously record a wide range of measurement values (cf. also storylines 4 to 6). All of this data is generated at 2.5 to 60-minute intervals and combine to produce the aforementioned total volume of measurement values. All of the data generated by these systems is ultimately processed in a cross-domain data warehouse, the ASCR data centre.

By evaluating this data, the ASCR pursues the objective of being able to determine which technology combinations are the most efficient and how each combination affects the behaviour of end consumers as well as of building and grid operation. The ASCR partners also expect to gain insights into the interdependencies between the underlying systems. This should also enable them to improve their existing service portfolios.

Initial situation – a dip in the "data lake"

The "journey" undertaken by every single measured value starts from a sensor and ends in data analysis. Depending on where a measurement is taken, however, its journey may be different: it might travel via electrical cables, along fibre-optic cables or through the building management system to reach the ASCR data centre. Even during this journey, some data streams branch off and are analysed in the intelligent transformer stations distributed throughout the grid. Software applications can, for example, determine the structure of the power grid without precise knowledge of its current layout. This means grid operators can survey the topology of existing grids in an automated process and benefit from significant time and cost savings.

On arrival in the data centre, measured values initially land in the so-called "data lake". Like fish, the values "swim" in an immense "data lake" and are examined by the evaluation mechanisms. In an initial step, an unstructured analysis is conducted to examine whether they display any deviations or special characteristics. The aim is to identify patterns in the data world.

Target function – a Q&A game?

A structured analysis of the data is performed following the initial data analysis, primarily to identify errors or gaps in the data. How much energy or CO_2 can be saved in a modern school or residential building? How can urban buildings efficiently participate in the energy market – and what effect will this have on grid operation? The ASCR research catalogue contains around 200 such questions. The results of the data analysis serve, on the one hand, as the basis for optimising grid planning processes and estimating potential grid overloads ahead of time. On the other hand, in the building sector, for example, models can be derived from this data – such as models for the optimal dimensions and layout of solar power systems in order to guarantee certain feed-in rates and potential revenues.

But where is the added value? What is the benefit of collecting and analysing this wealth of data – in compliance with data privacy regulations, of course?

The justification is: even data that might appear to contain little information can be valuable. We can use it to derive recurring patterns, such as the fact that a malfunctions always occurs when a particular switch is turned on or off. This can be a useful indicator for building managers and help them to track down faults. If we were to record only the data we knew we needed in advance, it would not be possible to locate faults or carry out predictive maintenance.

Once all the measured values pass through these analytical steps, they arrive at the end of their journey (for the time being) and are stored in an archive. They can be retrieved at any time to validate or perform new analyses of the results, which are examined in further detail in the subsequent section.

Results

As mentioned above, smart information and communications technology (ICT) draws on all of the data collected from buildings and the grid – in accordance with data protection regulations – in order to identify any interactions and interdependencies within it. A number of research questions were defined and addressed in separate research projects. As a result, at this juncture, we can only present selected results from the power grid and buildings areas of analysis and how they interact.

Analytical results relating to power grids and buildings

In the course of the research, identifying and interpreting interdependencies within the diverse data pool proved a challenge. The information provided by the building management system was evaluated in order to comprehend the relationships between factors that influence both the grid and buildings. To do so, special algorithms had to be developed that were capable of analysing the data collected. The resulting information will also be of particular importance in future because, over the long term, renewable energy systems will have to be integrated to a high degree, especially in urban areas.

One research question concerns improving the interaction between local energy generation and demand with an intelligent low-voltage grid. Possible local overloads, perhaps due to market-led building operation, are forecasted on the basis of the collected data and potential bottlenecks in the coordination between buildings and the power grid are resolved. So, taking the example of buildings

Identifying switch positions in the power grid

If, in the near future, many buildings and electric cars become both electricity generators and consumers, the low-voltage grid will have to be optimally set up. More than 100 monitoring devices in ASCR's test beds record the current grid situation and, together with sensors in the buildings, weather data and other information sources, provide around 1.5 million measured values per day. The major task is generating meaningful insights from this volume of data. The ASCR team therefore developed software that uses the data to identify power flow in the low-voltage grid. For this work, the team was recognised as Inventor of the Year by Siemens in its Open Innovation awards category (see also the "Marketing" chapter, p. 120).

Today, the low-voltage grid is practically always still operated blindly. Distribution boxes on the streets contain manual switches to control energy flows. At present, there is only one way to identify the current switching status: service technicians have to document switching operations precisely or, if absolutely necessary, inspect the situation on site. The software developed in the ASCR solves this problem. Based on the of real measured values, it was possible to test how well the switch position controls the electricity supply. In future, it will also be possible to map grid topology with up to 85 % accuracy in an automated process.

that are equipped with innovative ASCR-developed technologies, a special building management system (cf. storyline 2) undertakes the task of coordinating the energy supply between the photovoltaic and solar-thermal systems and the heat pumps. In parallel, newly developed data-analysis models also provide services (e.g. for the power grid), e. g. by using data from energy consumption forecasts, energy generation and storage management (see example in box to the left).

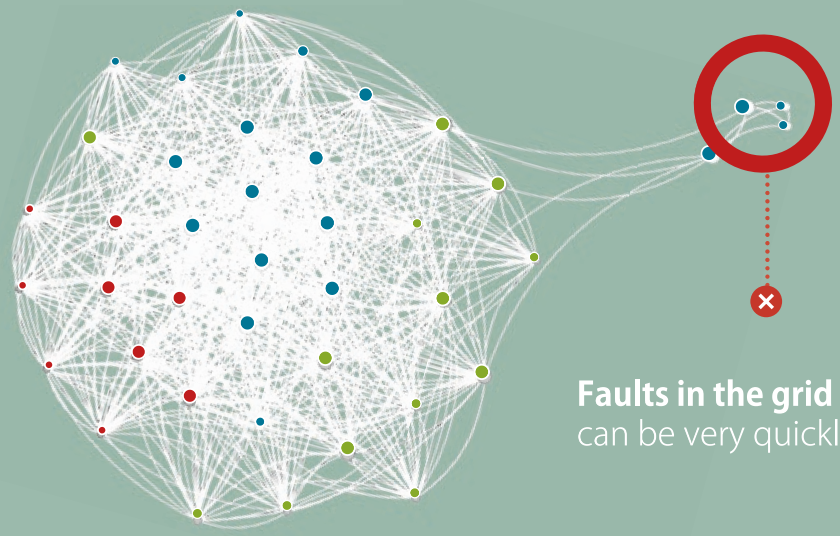
The aforementioned data analysis models use algorithms that learn from the knowledge they collect to improve themselves and adapt to new circumstances. These algorithms continuously refine the models and improve the control mechanisms in buildings and the power grid. The solutions and outcomes produced through the use of these algorithms can be summarised as follows:

- Wiener Netze have new models for load forecasting at transformer stations.
- A new web app has been produced that provides graphic depictions for grid status monitoring (e.g. voltage, asymmetry or passive energy).
- An automated process has been developed for distribution grid operators to assess the impact of connecting new consumer and generator loads.
- Automated methods are now available to monitor data quantity and quality (cf. also example given in further detail).
- There is proof of concept for a feasible future grid automation system that will integrate buildings.
- "Spectrum Power", Siemens' grid management tool for measurement processing and smart grid management, has been optimised.
- Power-quality measurement data has been automated for grid operators.
- Automatic anomaly identification (e.g. missing or faulty data) is now possible.
- An automatic process can analyse data to identify which generators are active in certain grid sections. Trend calculations for grid parameters (such as currents and power levels) can be produced, improving grid planning by identifying asymmetric loads.
- Domestic load model calculations for urban areas have been optimised (e. g. 12 % fewer errors, (i.e. savings of approx. 66 MWh/year) compared to standard load profiles in the ASCR smart grid test bed) and can be used in grid operation as well as energy trading.
- Short-term forecasts have been improved using data-based net load extraction and generation from total load (85 % accuracy).
- A state estimation for urban low-voltage grids and medium-voltage distribution grids can now be performed with over 96 % accuracy. This is an important requirement for implementing the correct control strategies in power grids.
- A loss estimate can now be performed for the medium-voltage grid with synthetic and measured load profiles.
- Furthermore, load profiles can be classified to identify representative consumers and prosumers.
- In addition, targeted data assessments can be performed to identify optimal locations for grid-friendly storage applications (cf. also storyline 6).

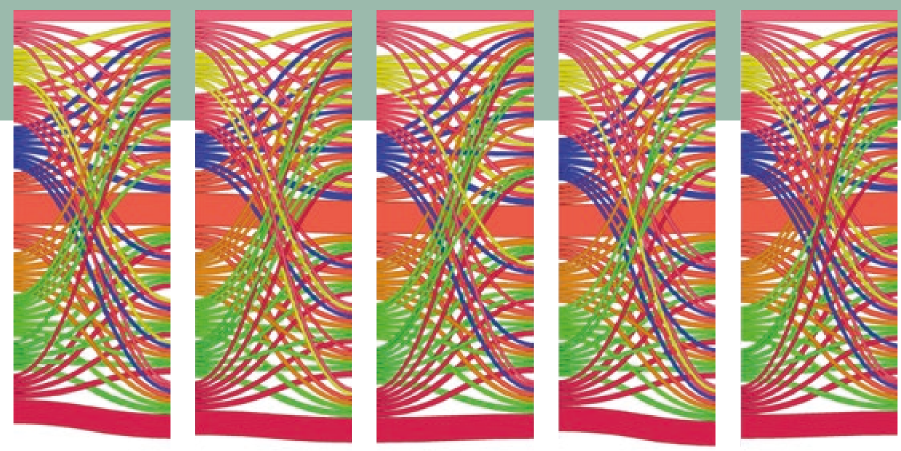
Data quantity and quality as an operational management tool

Identifying missing data and/or data errors is crucial for linked operational management of buildings and power grids. The failure to identify such data errors can lead to miscalculations. Therefore, corresponding data visualisations were developed to make it possible to evaluate data availability or changes by using a web application with graphic displays (e. g. in the form of a "heat map") (cf. figure below).

WEB APPLICATION WITH GRAPHIC DISPLAY (HEAT MAP) FOR DATA AVAILABILITY AND CHANGES



Faults in the grid topology
can be very quickly identified



SCHEMATIC ILLUSTRATIONS OF EXPLORATIVE DATA ANALYSES TO IDENTIFY GRID PARAMETERS AND STATUSES

DIFFERENT ASYMMETRIES OVER TIME

Explorative analyses can identify new and unknown interrelations within the data. Operating conditions that deviate from normal can be identified using practical analytical methods (e.g. neighbourhood analysis, sequence analysis or pattern identification). The figure above shows that, on the basis of these analytical methods, grid parameters such as asymmetry or topology can be identified very quickly, as well as changes to these parameters.

ASCR has also developed simulation models that depict the interrelations and dependencies between buildings and the power grid. Real values from test beds again form the basis for these models. ASCR connects data from different domains in the same way as other smart city projects and pilot initiatives. However, the added value generated by ASCR actually lies in the fact that data has not been connected in this manner to date. The simulation models ("digital twins") developed in ASCR deliver additional findings on individual operating conditions to the building and the power grid, as shown in the figure to the right. This made it possible for the implemented systems to accelerate error correction for the complex energy system in the residential building during commissioning. Many of the inefficiencies and errors identified by the monitoring system were not the fault of the complex energy system in residential building D12 but would also appear in conventional construction projects – where they remain unnoticed, however, entirely or at least for a long time. The implication is that the models developed will have to be placed in the foreground during the planning phase of large-scale construction projects to avoid such inefficiencies in advance.

Smart data analysis delivers cash benefits

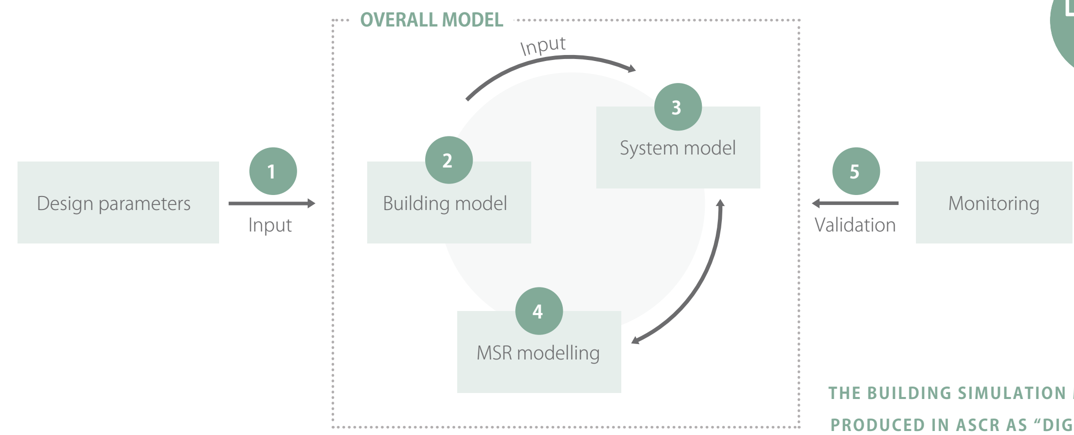
The analysis of building data and power grid data

generates cost benefits and boosts profiles for grid operators, building owners and energy suppliers (cf. in particular storylines 2, 3 and 4). For example, power consumption can be forecast each day for the following day. If the actual load on the following day deviates from the forecast, expensive balancing energy must be purchased if the systems developed in ASCR are not used. What is more, the rule for buildings is: the better the demand forecast, the more effectively local storage systems can be used and thus optimised in business terms. Furthermore, the developed systems can also support efforts to ensure a secure, fault-free energy supply, such as by promptly identifying anomalies in operating statuses. The data analyses performed and the models developed therefore help to minimise costs and maximise potential returns.

Summary and outlook

The data-analysis solutions developed in ASCR provide energy suppliers, grid operators and building operators with new analysis methods for status estimation and forecasting as well as new data visualisation options. These can be embedded in operating processes accordingly (primarily grid operation or building management) and marketing strategies (e.g. electricity trading).

Furthermore, as "digital twins", the simulation models offer the ability to determine the impact of altered parameters on different users. The use of data across different domains also makes it possible to perform a comprehensive, comparative analysis of an urban space in order to identify new interrelations in a complex urban system. A reference database such as this means that future variants or optimisations of building equipment, as well as changes to framework conditions (e.g. energy tariffs or building regulations), can be comparatively analysed and assessed for different stakeholders. The shareholders and their corporate partners can now use the new methods developed in ASCR directly to analyse data from different perspectives and gather their own insights. Other actors, such as the city administration, can use the system indirectly to find answers.



THE BUILDING SIMULATION MODELS PRODUCED IN ASCR AS "DIGITAL TWINS"

1. **Input data** - establishment of the planning parameters from the documentation files
2. **Building model** - thermal simulation building shell and heat output system (FBH)
3. **System model** - thermal modelling of the technical building installations
4. **MSR modelling** - illustration of the implemented control strategies and link to thermal models
5. **Validation** - of the models using monitoring data

ASCR marketing and results

The significance of targeted marketing and communications activities has risen steadily since the start of the research cooperation. ASCR has used intensive public relations activities to present itself as a capable enterprise and, in doing so, has promoted the image of its shareholders as innovators. The ASCR Demo Center rapidly emerged as a resounding success.

For the first few years of their existence, the work of the ASCR partners' research and development groups generally went under the radar. At the beginning, the fear that the cooperation would fail was simply too great. Yet, as the initiative produced its first successes, the pressure to communicate these grew, in line with the well-known motto "do good and talk about it".

ASCR received an unexpected boost at the start of its professional public relations activities. In hindsight, the idea of presenting the history, content and results of ASCR's research activities to interested audiences in a purpose-built Demo Center has proven to be the most powerful lever promoting ASCR's name recognition and the importance of its cooperation. Today, the positive effect of ASCR on the image of its shareholders cannot be overestimated.

ASCR uses different channels of communication

In close collaboration with the marketing and communications departments of its partners, ASCR uses different channels of communication to raise awareness of its services and successes among a wide audience.

The ASCR Demo Center

On around 60 square meters, the interactive showroom offers visitors the opportunity to explore the complex ASCR research development plan and all the facets of the underlying test beds.
A tour through the Demo Center clearly demonstrates how thermal and electrical energy can be efficiently generated, stored, distributed and consumed in an urban environment.

Presentations are tailored to the interests and level of expertise of the visitors. A media control system can display the research content as text, graphics, animations or videos; this makes it possible to explore topics in greater detail depending on the needs of the audience. This means that a specialist tour can be structured to be as informative as a tour for the general public.

Owing to the complexity of the topics addressed, Demo Center tours are mainly led by members of the ASCR core team, a task not foreseen in this form when ASCR was first conceived, and one that increasingly stretches ASCR's limited resources.

More than 300 tours have been given (at a rate of three to five per week) since the Demo Center opened in the summer of 2016. Delegations from every corner of the globe have visited and gained a comprehensive picture of ASCR's work. Guests have come from the fields of architecture, construction, local politics, urban design and the European Commission. In addition, ASCR has had the pleasure of welcoming many different energy suppliers and grid operators as well as many schoolchildren and students. The Demo Center was designed and constructed in cooperation with Linz-based media agency Vogel Audiovision GmbH and is supplemented and updated with new information and content on an ongoing basis.

Website, brochure and newsletter

The latest information and press releases are published on the ASCR website at www.ascr.at. The site's "social wall" displays all posts made online with

Advertising value of ASCR

ASCR issues press releases about important news and ongoing developments. This has generated considerable reporting in the media, including

- 352 media articles during the period of December 2013 to April 2018,
- 37.9 million potential reader contacts,
- which represents advertising value of around € 2.65 million
- and a positive tonality index.

TV segments (ORF show "Newton") and radio reports (Ö1 Wissenschaft) were not included in this advertising value calculation.
It can therefore be assumed that the ASCR's actual advertising value is somewhat higher.

the hashtag #ascr. A comprehensive, overall picture of the company and its activities can also be found in the ASCR brochure, which is available in both digital and printed forms in English and German. A regular newsletter ensures stakeholders stay up to date, with information about news and events.

Other media activities
Numerous posts and articles written by members of the research teams have been published in scientific publications, journals and magazines in recent years. Dozens of conference papers, discussion forums, presentations and radio interviews (Ö1 Wissenschaft, ORF show "Newton") round off the ASCR's comprehensive public identity. Here is a representative selection of examples:

- Lecture at the Smart City Expo World Congress 2017, Barcelona
- Lectures at various "Handelsblatt" events in Germany and Austria
- Contributions to Energy Utility Week in Amsterdam, 2017, and in Vienna, 2018 (including keynote from ASCR Management and chairing a panel discussion)
- Lecture at the Swiss Energy Congress 2017, St. Gallen
- Lectures and workshops at the University of Dortmund, 2016–2018
- Lecture at the Urban Future Global Conference, Vienna, 2017
- Participation in a panel at the Congress of the European Federation of Local Energy Companies (CEDEC), Brussels, 2018
- Lectures at the German Association of Local Utilities (VKU), 2017
- Participation in the Congress of the German Association of Energy and Water Industries (BDEW), 2017

Awards

Smart City Expo: In November 2016, at the world's largest smart city event – the Smart City Expo World Congress in Barcelona – the ASCR won one of three coveted World Smart City Awards,competing against more than 250 projects from 45 countries. ASCR was recognised as the world's Best Smart City Project 2016. The international jury were impressed by the integrative approach, which includes all components in a city's energy system – buildings, power grids, users and information and communication technologies – and thereby works towards an efficient, low-CO_2 energy future.

Smart Energy Systems Week Austria: In the summer of 2018, ASCR also won an award at the Smart Energy Systems Week Austria (SESWA). This event recognises exceptional achievements in applied research and development that make a significant contribution to the implementation of smart energy systems. ASCR was distinguished in the "Tech Solution" category.

SMART CITY PROJECT AWARD 2016

Shareholder marketing of ASCR

Over time, ongoing reporting by the shareholders has raised awareness and brought great recognition to ASCR's research activities.

Wien Energie GmbH
In the course of the ASCR research cooperation, Wien Energie trialled new services for its customers. Using the findings of these trials and the experiences of residents, Wien Energie is continuously optimising its services. Wien Energie communicates the latest results of the ASCR's research activities in a variety of ways – to target groups, customers and employees as well as media aimed at the general public. The company publicises ASCR topics online on its company website and at blog.wienenergie.at. The company's key channels of communication also include the "STADTleben" magazine (formerly "24 Stunden Energie!") for private customers and its business magazine, "Energie!".

Wiener Netze GmbH
In addition to the operational benefits, Wiener Netze has also benefited from the image-boosting and trust-fostering effects of Aspern Smart City Research – a project renowned beyond Austria's borders and unique in its practical execution. The insights gained through this work will soon make it possible to usher in a new energy era.

Wiener Netze raises awareness of ASCR through different internal and external communication channels, thereby raising the visibility of this innovative project.

The project is introduced in the cooperation and research section of its website at www.wienernetze.at; the ASCR is also a fixed part of its corporate presentation.

Wien 3420 aspern Development AG
As the development agency for aspern Seestadt, Wien 3420 aspern Development AG has placed importance on networking important players, seizing on new, smart stimuli and adopting sustainable urban concepts. Wien 3420 has found a perfect partner in ASCR. aspern Seestadt considers itself Smart City Vienna's urban lab, where intelligent concepts can be developed and tested. Working with the ASCR, we have the advantage of operating in a test bed that encourages and even demands fresh thinking from the ground up. We are implementing joint brainstorming workshops at the planning level; these have provided an innovative boost for a whole host of Seestadt projects. We also conduct joint communications activities – from congresses and trade fairs to media contacts and publications. ASCR is not just an innovation partner: it is living proof that aspern Seestadt is truly the urban lab of the smart city of the future. The countless international and national delegations we have received, who are explicitly interested in ASCR's research, confirm that our partnership has focused the spotlight on Seestadt.

Last but not least, ASCR works with end customers in the field of smart users. Its closest partners have been the tenants in the residential building. Of course, the requirements for communicating with these stakeholders are entirely different.

Siemens AG Austria
Siemens has communicated ASCR research cooperation to a wide audience and continues to do so. It does this in external media, e.g. many national and international print and digital media outlets, including both daily and specialist media, on TV and radio, online and on social media. The company also uses Siemens' own media channels, such as its research and customer magazines, online presences and newsletters. Hundreds of clients and partners around the world have already visited the research project and its Demo Center in Seestadt and been impressed by the unique nature of the research. When it comes to securing a sustainable position for Siemens products, solutions and research activities, aspern Seestadt is the ideal smart city project and is regarded as a showcase project for urban development in Austria, central and eastern Europe, and around the world. It shows that, as a partner to smart cities, Siemens is an integrated system supplier in possession of all key technologies and can therefore guarantee sustainability and secure energy supplies in urban areas. The Seestadt brochure, specially developed for the research project in German and English, provides general information about the project as well as technical details; we distribute it at all trade fairs, congresses and other events relating to building and power supply technologies. Siemens also presents the project in a manner accessible to a wide audience at the annual Seestadt Run, held in autumn.


FRIEDERICH KUPZOG FROM AIT (LEFT) AND ANDREAS LUGMAIER FROM SIEMENS AUSTRIA

Inventors of the Year 2017
Andreas Lugmaier from Siemens Corporate Technology and Friederich Kupzog from the Austrian Institute of Technology jointly conduct research on the integration of renewable energies in power grids. They test the technologies they invent for smart power grids in aspern Seestadt. The two researchers were recognised by Siemens as Inventors of the Year 2017 in the "Open Innovation" category.

Cooperation based on an equal footing – conclusions and outlook

Together and transdisciplinary

In December 2015, 195 countries signed a historic agreement in Paris in which they committed to keep the global temperature rise "well below" 2° Celsius. In terms of global CO_2 emissions, heavy industry (29 %) is the largest producing sector, buildings (18 %) are in second place and the energy needed for energy supply (15 %) ranks fifth. The "deep" decarbonisation of our planet demands rapid breakthroughs in technological areas, including building management, storage systems for renewable energies that are only periodically available, and sophisticated, internet-like power grids capable of transporting electricity from distributed sources to distributed users at different times. As a cooperative research project, ASCR has aimed to achieve meaningful progress in exactly these fields over the last five years.

Does joint research and development produce better results?

The question of whether joint, cross-company and transdisciplinary research "pays off" is not likely to ever receive a straightforward, conclusive answer. Numerous experts have already examined precisely this issue.[1] However, based on the experience in ASCR, it can be concluded that cooperation between different specialist fields, such as physics, energy engineering, electrical engineering, thermodynamics, economics, law and behavioural psychology can deliver unique results that one specialism alone would be unable to produce in this scope and depth.

The pressure for change in urban energy supply caused by rapid population growth has many parameters that must be taken into account. We would now like to examine a few aspects to demonstrate that energy research for the cities of the future requires a transdisciplinary approach.

Let us start where energy should ideally be generated for urban residents – that is to say, as close as possible to the consumer. Land is a rare commodity in this age of urbanisation and is not available without restriction for solar-thermal, photovoltaic and wind-power systems. We must therefore consider how buildings in particular can be used to generate energy. Urban designers and architects must ensure that future structures are conceived in such a way that as much space as possible can be used for energy generation systems. While this relates to buildings' roofs and façades, it also means ensuring that interior spaces are available for the installation of energy systems, e.g. heat pumps and energy storage devices. Spaces should also be set aside in buildings for systems that make use of waste air from car parks, gyms or classrooms. At the same time, it is important to consider the extent to which soil can be used to store solar heat from the summer for use in winter. Without such measures, it will be near impossible to supply buildings with eco-friendly heating – and, in future, cooling.

Working together with all relevant stakeholders, we must consider how urban and neighbourhood development can be best structured, for example in order to avoid negative mutual effects due to the use of groundwater as a heat source. Urban designers and the energy, construction, water supply and distribution sectors will have to work together to take advantage of opportunities to implement optimal energy use.

As ASCR trials relate to systems that will have to function properly over the long term, they must attain a minimum level of economy – even as the subjects of a research initiative. This means that economic aspects are considered in both the planning phase and in work to optimise systems during research operation to determine which are suitable for further development to market-ready solutions and, as the case may be, to stop work on other projects in good time. We must ensure that the funds provided from public sources and from corporate partners' core operations are also used efficiently. Social research must, in turn, accompany such efforts and ensure that implementation of the solutions conceived by technology experts will deliver sustainable benefits for users. To do this, future users must be engaged at an early stage through social research and ongoing cross-checking with all other disciplines.

1 Philipp W. Balsiger: Transdisziplinarität. Systematisch-vergleichende Untersuchung disziplinübergreifender Wissenschaftspraxis. Fink, Munich/Paderborn 2005, ISBN 3-7705-4092-1, Matthias Bergmann, Bettina Brohmann, Esther Hofmann, M. Céline Loibl, Regine Rehaag, Engelbert Schramm, Jan-Peter Voss: Qualitätskriterien transdisziplinärer Forschung. Ein Leitfaden für die formative Evaluation von Forschungsprojekten. ISOE-Studientexte, No. 13, 2005.

What happens to the results of ASCR's development work? Who bears responsibility for them?

"Plant early if you want to enjoy the harvest."
This saying is as true for research and development as it is for agriculture. Proper sowing, favourable weather and constant nourishment and care of delicate young plants are critical to enjoy a successful harvest. The ASCR R&D programme includes numerous detailed research questions and represents a key starting point for all our activities. On behalf of the project's partners, the ASCR research teams develop concepts and solutions and implement prototypical systems in suitable test beds.

The working structure behind this is complex. The research and development programme is a joint effort and should also be jointly implemented by the responsible project leaders, who are appointed by the shareholders. The technological specialists in Siemens' working groups therefore have to cooperate closely with teams responsible for implementation at Wiener Netze, Wien Energie and in Siemens' front-line Building Technology (BT) and Energy Management (EM) units.

As a cooperation platform, ASCR provides the necessary framework for a structured exchange of experiences and outcomes. This also includes providing suitable methods to facilitate the desired outcomes (programme and project management), overcoming interpersonal barriers and breaking down differences in corporate cultures. ASCR is ultimately also responsible for using funds efficiently and must continuously ensure the relevance and efficiency of the research and development programme. Responsibility for achieving valuable research results is therefore not placed solely on ASCR's shoulders, but also on all the shareholders. The same applies to whether and when the prototypes are actually developed into market-ready products.

Recommendations and the use of research results

Use of expertise and research results by shareholder
The use of research results is extensively regulated in the cooperation agreement, the development framework agreements and in ASCR's personnel secondment contracts. These policies also take into consideration how partners should handle expertise and any existing proprietary rights. The last point is particularly important to the project's technology partner, Siemens, so much so that this aspect was attributed great importance in the preparation of the cooperation agreement.

The shareholders granted each other extensive rights of use for the jointly developed research results. The right to commercial exploitation of the results is secured and regulated in a balanced way – as far as is legally possible – for all corporate partners participating in ASCR.

On the basis of the decision-making process described above, all participating partners can develop and implement their respective products and service processes. The importance of regular coordination regarding the legal relevance and contractual classification of developments and results grows as the research term progresses as the partners prepare to use the results at an early stage and as they are produced. The ultimate aim is for the results of joint research activities to bear benefits rapidly.

Benefits of ASCR expertise for the City of Vienna
The direct use of the commercially exploitable expertise described above is subject to legal restrictions due to the role of Wien Energie and Wiener Netze as shareholders and, therefore, the direct participation of the City of Vienna. However, there will certainly be valuable benefits for the City of Vienna if the project's shareholders – Siemens, Wien Energie and Wiener Netze – apply in practice the expertise they have gained and, in the process, this expertise actively contributes to securing high-quality jobs. By combining the complementary strengths of three major companies, the City of Vienna achieves a high profile in issues of urban development. Indeed, that the public authorities engage in a research cooperation involving two publicly owned companies and an international technology group to solve pressing problems for the future of the energy industry is unique anywhere around the world. The model has received worldwide attention. Proof of this can be found in the

numerous visits to Seestadt by international delegations (see also the "Marketing" chapter, page 120).

Closer to home, some offices of the City of Vienna have asked the ASCR's advice about clarifying energy sector issues smart city. ASCR is happy to oblige and, in this way, is constantly enhancing its consultancy skills in relation to municipal issues.

Transdisciplinary results as the basis for the following research period, ASCR 2.0

One rather unsurprising outcome from the smart user research domain is that the constraints of users' daily routines mean that, in spite of technical aids such as smart home control or smart home automation, there is little scope for users to make active decisions. The data collected also indicates that there is little potential to shift loads in future by changing user behaviour. Consequently, there were intensive – and thoroughly controversial – discussions inside ASCR as to whether and to what extent smart users can actually contribute to the changes needed in the energy future in combination with buildings acting intelligently. Despite various reservations, we ultimately decided to continue involving smart users actively in our research, develop further approaches for them in the ASCR 2.0 research programme and sound out their prospects of efficacy and public acceptance.

Especially the information about building quality from social research motivates ASCR to collaborate more closely with building contractors to achieve improvements in the structural and technical configuration of buildings. Users have repeatedly criticised the (dis)comfort in the school campus and the apartments on plot D12 in summer. The facilities overheated during the warm season, leading users to purchase air-conditioning units or ventilators – a move that negatively affects the use of building flexibility. So, in future, we will pay greater attention to aspects of water-based cooling systems.

In addition to classic research, it will also be very necessary to convince all the stakeholders involved in urban development that high building quality and intelligent, predictive control systems in smart buildings are increasingly important. One of ASCR's stated aims is to use the meaningful results from the smart building research domain to further develop the building energy management system (BEMS) and make the experience gathered in installation, commissioning and maintenance available to interested building contractors.

The widespread application of intelligent building control technology we expect to see in future can form a stable basis for Wien Energie and Wiener Netze to market building flexibilities. Other partners on the building contractors' side must be convinced of the merits and integrated in a timely manner to actually achieve the flexibility potential calculated in the first research phase and make it economically accessible, while long-term experience must also be collected over several seasons.

The analysis and forecasting tools developed in the smart ICT research domain have already been installed for testing in grid planning and operation.

The results produced so far therefore form an excellent foundation upon which to push forward with our work on the most pressing energy research issues of our time.

Outlook – ASCR 2.0 research programme

Continuation a successful cooperation

Developing adequate responses to issues of future urban energy supplies requires a development environment that reflects reality as closely possible and allows different approaches to be examined on an ongoing basis to assess their suitability in practice. In the first phase of ASCR (2013–2018), we created an ultramodern infrastructural foundation that makes it possible to display complex interdependencies. In addition to the capital expenditures to date, its value lies in a cross-domain "wealth of data" that would require enormous effort to reproduce and that, therefore, must not be lost under any circumstances.

The Aspern Smart City Research (ASCR) cooperation platform established by Siemens, Wien Energie, Wiener Netze, the Vienna Business Agency and Wien 3420 is the perfect foundation for further research in this crucial field. The agreements for ASCR 2.0 (2019–2023), which were signed at the end of October 2018, ensure that ASCR will continue to provide innovative test beds for research-intensive work on the urban energy system of the future. Its organisational structure – a mixture of programme management, project management, funding project processing, research operation and classic business management – remains a reliable guarantee that objectives can be achieved.

The overarching aim of the work in the new ASCR phase must be to put solutions into practice on the ground. Added-value for the partners generated from the research questions and results of development work should, if economically viable, be turned into products that will be deployed in daily operations in the next five years.

The processes of amending and updating standards and regulations will have to be accelerated to accommodate the pace of technological progress; they must not hinder progress and must instead contribute to creating a caring, prosperous and sustainable society. ASCR can proactively work to draw up the necessary regulatory conditions. ASCR can test different scenarios and ensure pragmatic implementation that provides benefits to all stakeholders.

Research, in particular in the smart grid research domain, can quickly be confronted by regulatory requirements – e.g. as because operating electrical storage systems are currently subject to strict standards that, in light of the results of research to date, it might be prudent to adapt. Consequently, ASCR intends to involve E-Control Austria (ECA) closely in the search for regulatory innovations.

The increasingly high degree to which production systems, storage devices, grid components and different sensors have become integrated over time to form highly complex systems has made it necessary to develop "plug & automate" solutions in order to reduce roll-out costs (for installation, operation and maintenance of the system as a whole). Insights from analysis of the ever-growing volume of data (big data) will form the basis for all modern operational management approaches. This is why, in ASCR, we continuously develop and test new methods to use, for example, big data and industrial IoT (Internet of Things), as effectively as possible to implement new business models. This includes, of course, considering new, ultramodern security concepts to counter cyberattacks.

The increasingly reciprocal impacts of different research domains due to networking and integration will also require users to be more willing to be integrated in the technologies and communications of a smart city's modern energy supply system.

ASCR is a globally unique research project in which companies supplement each other's strengths and work together with the city administration and engaged residents to conduct research into system solutions. In addition, to achieve the lofty aims set, countless interfaces will have to be taken into consideration and the interaction of complex system components controlled. Each shareholder can develop part of the system solution for their own use; the long-sought energy transition will, however, only become practical reality through concerted, collective effort. ASCR pools the competencies needed to achieve this and therefore acts as an "enabler" of the efforts to make the new, sustainable energy future a reality.

The technological progress made in the four research areas (smart grid, smart building, smart user and smart ICT) has attracted international prestige and enjoys an outstanding and progressive image. The ASCR Demo Center is visited by hundreds of visitors from all around the world every year. Publications in well-known specialist magazines and presentations at various conferences and congresses regularly receive high praise from these audiences. An absolute highlight in this regard was winning the Smart City Award 2016 for Best Project – a coveted price presented each year at the Smart City Expo World Congress in Barcelona.

Outlook for future research activities

The new ASCR 2.0 research and development programme can be roughly divided into four main topic areas. The Viennese utility companies and their duties (energy supply, grid operation) will continue to be a focus, as will the city as a whole. The programme's main strategic priorities are:

- **Comfortable living and work**
  ASCR's research aims to offer innovative solutions for the future of urban energy. It will only be possible to implement new concepts successfully in the market economy when they satisfy a need or solve a pressing problem. ASCR follows this principle in its work. As our homes and workplaces are central aspects of our lives, ASCR has set itself the objective of providing efficient solutions for application in these spheres, in particular in terms of the energy industry. We therefore not only aim to have a societal impact but also enable, above all, ASCR shareholders to shape the energy world of the future by becoming "first movers".

- **Data management: sifting "mounds of data" to gain a "wealth of data"**
  Integrating high numbers of different data sources in a standardised system while monitoring the quality and quantity of this data through automated processes is a deeply complex task. In ASCR, we aim to make all data available in as simple and straightforward a form as possible so that analyses can be performed in a prompt and targeted manner. Data security and privacy still remain our utmost priority.

- **Efficiency gains: "system disruption through digitalisation"**
  Digitalisation will advance rapidly in coming years, particularly regarding power grids. Technologies that have been partially implemented, such as "plug & automate", data analytics and automated ICT security, will continue to be developed and tested in the overall system to achieve a homogeneous procedure across all levels. For Wien Energie, as a company active on the energy market, it is hoped that the research results will provide a basis for establishing personalised offers, services or even complete energy solutions for (major) customers.

- **Local, optimised energy system**
  Creating sustainable, integrated energy systems that are fit for the future is the focus of activities in ASCR 2.0. ASCR is already conceiving ideas to optimise private use of shared PV systems. For example, Austria's first tenant electricity system is currently being planned for the Vienna Business Agency in the Aspern Technology Centre. We hope that the idea of a genuine "anergy network", which connects several smart buildings through a water-based heating and cooling supply system, will provide new insights for the development of inner-city energy solutions. ASCR in cooperation with with Wien Energie and Siemens will work more intensively with innovative building contractors to achieve this.

The ASCR 2.0 research programme must not be the end of the story

The ASCR 2.0 research and development programme, technology streams and use cases are described in detail in the "ASCR 2.0 R&D Programme" document. This is the framework for all activities, which will then be summarised in a comprehensive final report like this one at the end of 2023. ASCR blends together the cultures and expertise of three major companies. By 2023, after almost a decade of joint research, we will be able to apply the immense pool of empirical data to address the future issues of smart cities – issues which are only becoming more complex – even more expediently and with even greater precision. ASCR's integration in the City of Vienna's smart city process also benefits from a wide-ranging understanding of the issues beyond the energy industry. Given that a robust and sustainable urban energy supply system – a system that ASCR and its shareholders would like to develop – is the basis for all increasingly digitalised smart city applications, ASCR will serve in future as an interesting basis for the development of other innovative initiatives.

PROPRIETOR AND PUBLISHER	Aspern Smart City Research GmbH & Co KG (ASCR) Technologiezentrum Seestadt Seestadtstrasse 27/2/Top 19, 1220 Vienna +43 1 908 93 69, office@ascr.at, www.ascr.at
EDITING	Aspern Smart City Research GmbH & Co KG (ASCR)
CONCEPT AND TEXT	ASCR, Siemens, Wien Energie, Wiener Netze, Vienna Business Agency, Wien 3420
PROJECT MANAGEMENT	Oliver Juli (ASCR)
EDITORIAL TEAM	Robert Grüneis (ASCR) Georg Pammer (ASCR) Oliver Juli (ASCR) Melisa Kis-Juhasz (ASCR) Wolfgang Prüggler (MME) Susanne Geissler (SERA)
CONTRIBUTORS	Andreas Schuster (ASCR) Ines Weigl (ASCR) Nicole Kreuzer (ASCR) Robert Hammerling (ASCR) Martin Svaricek (ASCR) Roman Tobler (ASCR) Christopher Kahler (Wiener Netze) Roland Zoll (Wiener Netze) Alfred Einfalt (Siemens) Lukas Krammer (Siemens) Gerhard Engelbrecht (Siemens) Siegrun Klug (SERA) Natalie Prüggler (MME) Dagmar Hemmer (communication matters)
ART DIRECTION AND DESIGN	Maria Lechner
JOURNALISTIC SUPPORT	Klaus Fischer
COPY-EDITING	Johannes Payer
TRANSLATION	Nativy Translations
INFOGRAPHICS	Vogel AV, APA Auftragsgrafik
PHOTOS	APA-Fotoservice, Andi Bruckner, communication matters, Ian Ehm, Emakina, Kurt Keinrath, Philipp Lipiarski, PID, Bernd Richter, Peter Rigaud, Walter Schaub-Walzer, Vogel AV
CORPORATE LOGOS	ASCR, Siemens, Wien Energie, Wiener Netze, Vienna Business Agency, Wien 3420
FUNDING PROJECT LOGOS	SCDA (ASCR), iNIS (AIT), FACDS (Wiener Netze)
PRINTING	AV+Astoria

www.ascr.at