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Smart Building Networks

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Summary

Smart Building Networks

This paper gives insight into the paradigm of Smart Grid with focus on the smart building as its fundamental part. After a theoretical description of a current grid's evolution to smart form as well as basic features and functionalities of a smart building, a draft model of the building has been developed in the AnyLogic program. It simulates the behaviour of a smart building and possibilities it can provide to the grid through various scenarios. In the end, a cost and benefit analysis has been conducted to show expenses and revenues in case of implementing a smart house at different locations (Norway and Croatia), and profitability of such a project.

This assignment is realised as a part of the collaborative project "Sustainable Energy and Environment in Western Balkans" that aims to develop and establish five new internationally recognized MSc study programs for the field of "Sustainable Energy and Environment", one at each of the five collaborating universities in three different WB countries. The project is funded through the Norwegian Programme in Higher Education, Research and Development in the Western Balkans, Programme 3: Energy Sector (HERD Energy) for the period 2011-2013.

Keywords: smart, grid, city, building, behaviour, features, functionality, model, simulation, costs, benefits

Summary in Croatian

Pametne mreže u zgradama

Ovaj rad daje uvid u paradigmu pametne mreže s naglaskom na pametnu zgradu kao svoj temeljni dio. Nakon teoretskog opisa evolucije postojeće mreže u pametni oblik te osnovnih značajki i funkcionalnosti pametne zgrade, razvijen je model zgrade u programu AnyLogic. Model simulira ponašanje pametne zgrade i mogućnosti koje ona može pružiti mreži u raznim scenarijima. Na kraju je provedena analiza troškova i koristi kako bi se prikazali izdatci i prihodi pri implementaciji pametne zgrade na različitim lokacijama (Norveška i Hrvatska) te isplativost takvog projekta.

Rad je ostvaren kao dio zajedničkog projekta “Sustainable Energy and Environment in Western Balkans” koji ima cilj razviti i uspostaviti pet novih međunarodno priznatih diplomskih studija u području okoliša i održivog razvoja, jedan na svakom od pet suradničkih sveučilišta u tri države zapadnog Balkana. Projekt je financiran kroz program vlade Kraljevine Norveške za visoko školstvo, istraživanje i razvoj u zemljama zapadnog Balkana, Program 3: Energetski sektor (HERD Energy) u razdoblju 2011.-2013.

Ključne riječi: pametna, mreža, grad, zgrada, ponašanje, značajke, funkcionalnost, model, simulacija, troškovi, korist

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Abbreviations

AC	*Alternating Current*
BAS	*Building Automation System*
BEMS	*Building Energy Management System*
DR	*Demand Response*
DSM	*Demand Side Management*
EU	*European Union*
FACTS	*Flexible Alternating Current Transmission System*
GE	*General Electric*
HAN	*Home Area Network*
HVDC	*High Voltage Direct Current*
IBM	*International Business Machines*
ICT	*Information and Communication Technology*
IEEE	*Institute of Electrical and Electronics Engineers*
LAN	*Local Area Network*
NIST	*National Institute of Standards and Technology*
NPV	*Net Present Value*
PMU	*Phasor Measurement Unit*
PV	*PhotoVoltaic*
TS	*Telecommunication System*
UK	*United Kingdom*
UPFC	*Unified Power Flow Controller*
US	*United States*
WAMPAC	*Wide Area Monitoring Protection And Control*

1. Introduction

Current electric power system has been established over the past century and has been designed to produce electricity at large generating units and deliver it to the consumers through the transmission and distribution grid, sometimes over considerably large distances. This system does not have a good communication network that could ensure its effective operation and security, enable market transactions or provide active interaction between loads and the system. The revolution in communication technology offers the possibility of monitoring and controlling every part of the grid which results in flexible and lower cost operation. But, due to the huge size of the power system and significant investment costs, it is necessary to carefully study and justify the changes.

If you asked 10 people what a Smart Grid is, you would probably get 10 different definitions. It is impossible to exactly define the Smart Grid considering it is not a single concept or a single technology but it consists of so many different layers. Thus, the interpretation depends on the viewer's perspective. Some definitions of a Smart Grid are given below:

- *"A Smart Grid integrates advanced sensing technologies, control methods and integrated communications into the current electricity grid."* [1]
- *"Smart Grid is an automated, widely distributed energy delivery network characterized by a two-way flow of electricity and information, capable of monitoring and responding to changes in everything from power plants to customer preferences to individual appliances."* [2]
- *"The Smart Grid takes the existing electricity delivery system and makes it 'smart' by linking and applying seamless communications systems that can: gather and store data and convert the data to intelligence; communicate intelligence omnidirectionally among components in the 'smart' electricity system; and allow automated control that is responsive to that intelligence."* [3]

What emerge from these definitions are three key words: sensing, control and communication. These are crucial elements that will enable progress of the current grid and evolve it to the grid of the future. Not only does the Smart Grid implicate real-time measurements, integration of distributed resources and controllable loads as well as advanced communication technology that enables two-way power flow, it also has numerous characteristics that provide more efficient, more affordable and more sustainable energy supply. The following attributes have to be fulfilled in the Smart Grid [4-6]:

- The grid has to be absolutely reliable and provide power to the users when needed;
- The grid has to assure optimal power quality for all consumers who require it;
- The grid has to be absolutely secure and withstand attacks without suffering major blackouts;
- The grid has to assure the lowest cost through optimal use of bulk power generation, distributed resources, storages and controllable loads;
- The grid has to be more efficient (reduction of transmission and distribution losses, efficient power production, increase in efficiency of end users);
- The grid has to reduce environmental impacts through improvement in efficiency and integration of intermittent resources; and
- The grid has to monitor all the critical components to enable automated maintenance and outage prevention.

1.1. Reasons for implementation of Smart Grid

In the past decade there has been an increasing interest in the Smart Grid. One of the principal reasons is information and communication technology that is developing rapidly and can significantly modernise the operation of current electric networks. Also, the preservation of the environment is a major global concern as the carbon-free society is one of the requirements for sustainable development. The Smart Grid will enable integration of renewable resources as well as monitoring and controlling existing bulk generation that will lead to minimising the CO_2 emissions in the power system. In addition, there are number of other reasons for implementation of the Smart Grid that are listed below [7]:

- In many parts of the world the transmission and distribution equipment is in need of replacement which is an opportunity to modernise it with new innovative technology;

- In many countries there is a lack of capacity in the distribution system so a part of renewable generation can not be connected to the grid. This is why more intelligent methods of increasing the power transfer capacity should be obtained;
- The power system works within prescribed voltage and frequency limits that have to be obtained at all times. The distributed generation can cause over-voltages at time of light-load and it has variable output that can not be predicted with certainty so it can lead to imbalance of demand and supply causing frequency variations. Thus, it is necessary to introduce flexible loads and energy storage as a part of system reserve to maintain network stability;
- The society requires reliable electricity supply as more and more critical loads are connected. It is well known that the Value of Lost Load is several times bigger than the cost of electrical energy which leads to installation of additional redundant power lines. The Smart Grid uses intelligent post-fault reconfiguration so that after the inevitable faults in the system, the supply to the customers is maintained. At the same time, it decreases the need of redundant circuits that may be only partly loaded for the most of their lifetime;
- Many national governments are encouraging the Smart Grid through various incentives. The SmartGrid Technology Platform of the European Union has published a strategy for the European network of the future [8] which has identified many important areas for utilisation of renewable energy, energy efficiency and carbon reductions. Among others, it includes developing decentralised architectures for system control, advanced communication technology, active demand side and integration of intermittent generation.

Maybe the most important part of the Smart Grid is a smart building. It is one of the fundamental parts considering that every house, every office and every commercial building will be transformed into this form. Hence, it is very important to understand the parts and functioning principles of a smart building. For researchers it is difficult to work and analyse a real smart building since home appliances, sensors and other crucial parts are very expensive. Therefore, various models are developed to simulate the behaviour of a smart building under different circumstances and to become acquainted with the possibilities it can provide to the grid.

This paper will describe the basic features of Smart Grid and smart buildings as well as the possible evolution of existing cities to the smart form. A draft model of a smart house will also be developed to show basic features such as demand side management and reduction of electricity bill with regard to the production from renewable resource and storage capabilities. In the end, a short cost and benefit analysis of a smart house will be given to show the possible expenses and revenues in case of transforming a house to smart form.

2. The paradigm of Smart Grid

2.1. Basic building blocks of Smart Grid

According to NIST[1], Smart Grid is consisted of seven building blocks shown in the figure (Figure 2.1, [9]). These are [10]:

- Bulk generation;
- Transmission;
- Distribution;
- Customer;
- Markets;
- Operations; and
- Service provider.

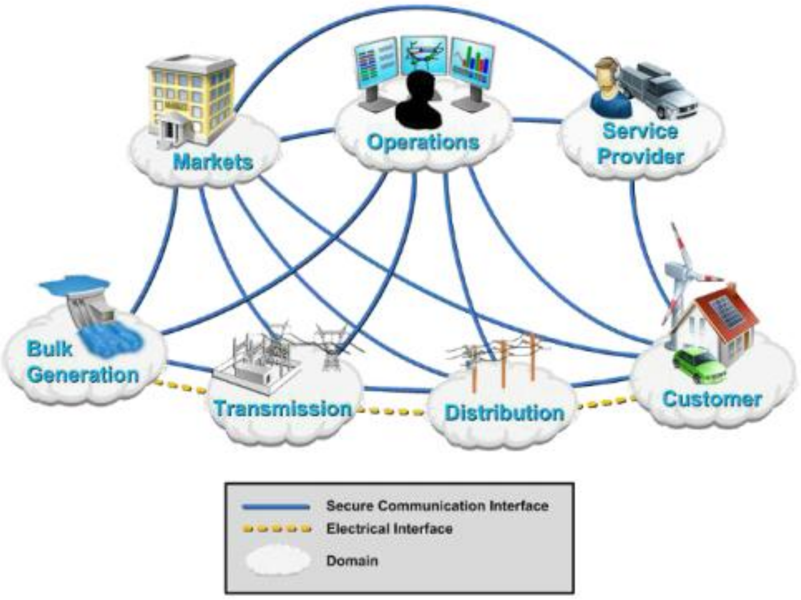

Figure 2.1 Building blocks of Smart Grid [9]

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[1] National Institute of Standards and Technology

The bottom four blocks in the figure are bulk generation, transmission, distribution and customer. These blocks already exist, but they will have to be improved by addition of some "smart" characteristics. Conventional power plants like gas turbines, coal-fired power plants, nuclear power plants and hydro power plants will still be in operation. However, there will be a more diverse mix of electricity generation considering the number of renewable resources will greatly increase. This means that the transmission network needs reinforcement in terms of real-time voltage and angle stability, reactive power control, fault analysis and control of power flows.

The biggest changes have to be made to the distribution grid as the consumers will become active members that can feed power back to the grid. Smart distribution solutions are designed to minimize energy losses and optimally utilize distributed energy sources and energy storages. These solutions cover variety of applications in the distribution automation such as Volt/VAR control and optimization, transformer monitoring, substation automation, line switch automation, and fault detection, identification and recovery [11]. With two-way communication between the capacitor banks at the substation and the utility, the process of switching the capacitors banks on and off can be fully automated bringing to minimal VAR losses as well as maintenance of voltage levels. The transformers provide critical function of stepping voltages down but there is a lack of visibility into their status until a failure occurs. Introduced two-way communication can be utilised for monitoring transformer voltage and current but also for monitoring oil levels and temperatures which can indicate a malfunction and with corrective actions prevent destruction of these expensive components. Distribution network can provide enhanced functionality of every part of the system by central monitor and control provided by the aforementioned two-way communication [12, 13].

The customer will also experience great changes but this will be discussed in detail in the following subchapter.

Three new blocks will be introduced to the existing system within the concept of Smart Grid – markets, operations and service provider. The markets domain operates and coordinates all the participants in the electricity markets, provides market management, wholesaling and trading of energy services, interfaces with all other domains and ensures they are coordinated in a competitive market environment. By introducing smart metering and demand response, the market will become a fast changing landscape with significantly greater number of stakeholders which will eventually result in higher, if not almost perfect, competition and lower prices of electricity.

The operations domain will get very complex because it manages and controls the electricity flow of all other domains. In the context of Smart Grid, it is allowed to individual homeowners to sell power back to the grid but the utility also has the ability to send signals for controlling customer’s appliances. The operations in the present state deals with operating hundreds of substations while by expanding to Smart Grid this number will amount to millions. Of course, it can not be expected that the power company will deal with individual homeowners. Hence, that is the reason for introducing the last but not least building block of the Smart Grid – service provider. Service provider is a group of people or business who will work with individual homeowners and aggregate the availability of renewable resources or storages to give a substantial quantity of power with what the power company can work. A 5 kW saving in one house is below noise level for a big power company which means they will not have any profitability by controlling it. However, a service provider can aggregate thousands of such homes providing the utility with a number of megawatts. This way, the power company will be interested in controlling such a load for decreasing the total consumption in peak hours.

2.1.1. Customer as the most complex part of the grid

The final and the most complicated building block of the Smart Grid is the customer. The technology itself is not the only problem in implementing Smart Grid solutions to the customer domain. The consumers’ attitude towards smart metering is as equally important as the technology if not even more important. If the consumers are not willing to implement smart meters and smart appliances into their homes, the evolution of the power grid will not get very far. Hence, education is very important to increase people’s awareness of energy consumption and ways they could profit from Smart Grid. A survey conducted in the United Kingdom [14] shows that a majority of the respondents did not know which of their appliances consumed most energy leading to the conclusion that it is unlikely these users will reduce their energy consumption. Therefore, it is necessary to conduct active feedback on consumption to form new habits in people’s behaviour with regard to energy conservation. On the other hand, a survey supported by European Commission [15] was conducted in five European countries (Austria, Germany, Italy, Slovenia and UK) to see how high the rate of acceptance of smart appliances is. In general, the acceptance level is rather high in all countries as they believe new technical solutions will make their lives more comfortable. However, most of the respondents stated they would not buy smart appliances because of their functions but only if they needed a new one anyway. Furthermore, the study reveals that the economic advantages are far more imperative for the users than the ecological ones. General attitudes towards smart appliances are given in the figure (Figure 2.2).

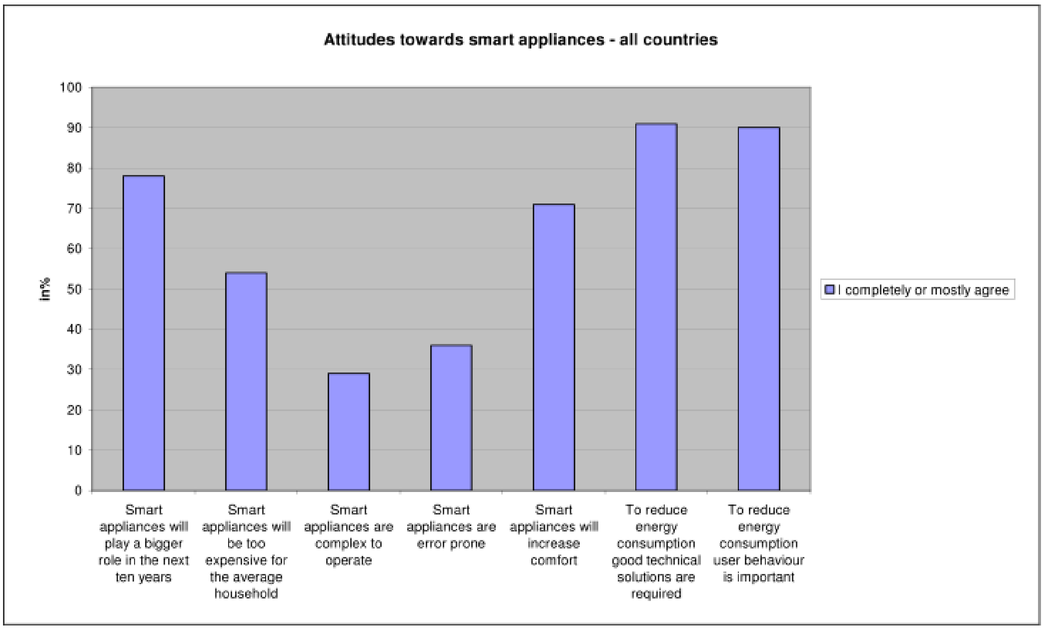


Figure 2.2 Attitudes toward smart appliances according to [15]

Despite the overall positive opinion, major barriers for implementing smart appliances are safety fears and privacy issues. Customers do not feel comfortable with leaving their appliances switched on when they are not at home as they are afraid of break-downs that might lead to flood or fire. This is generally caused by lack of understanding of operational principles which can easily be solved by further education of the end-users. Another major concern for consumers is security issue as malware can infect the grid and through the two-way communication affect the consumers and tamper with their appliances or electricity bill. The solution to this problem is more complex and is a part of a larger system for security of the entire network from cyber attacks [16]. Maybe the biggest concern for the consumers is privacy. Automated metering infrastructure may disclose information about what the homeowners are doing and when. This is unacceptable for the consumers who want to maintain their privacy and don not want the power company knowing which of the appliances are currently switched on. A simple solution to this problem is a controller at a household level which will monitor the performance of all devices. This way the power company will interface with that device through smart meter to do overall load preference but will not know what the state of each smart appliance is. Additionally, considering the Smart Grid context, any type of energy use data linked to personal information such as account number, meter reading or lifestyle should be secured and monitored in the proper way. Various models are being developed to obscure usage pattern of an individual appliance, e.g. ElecPrivacy model [17] which uses power router and rechargeable battery, essential parts of every smart building.

In the concept of Smart Grid every customer, i.e. consumer, will become an active member not only by producing electricity with renewable resources but also by a demand response program. The two-way communication will, among other things, allow the utility to send a signal for load reduction during the peak hours, e.g. to shut down the electrical water heater (Figure 2.3 [18]). Of course, the customer must have the possibility of accepting or refusing the reduction request. This will be possible through smart meter's interface where the customer will have insight in current consumption, electricity prices, requests from the utility and many more. This way if the customer's current wish is to use all active loads at that precise time, he could refuse the request and the utility would forward it to another customer. However, there will certainly be customers that do not want to keep track of electricity prices themselves or respond to the utility's requests on their own, so called "set and forget" approach. For them, the smart meter will have an automatic reply option. The customer just has to enter his predispositions about load management and the highest price he is willing to pay, and the smart meter will automatically manage the loads with regard to the price as well as reply to the utility's requests [19].

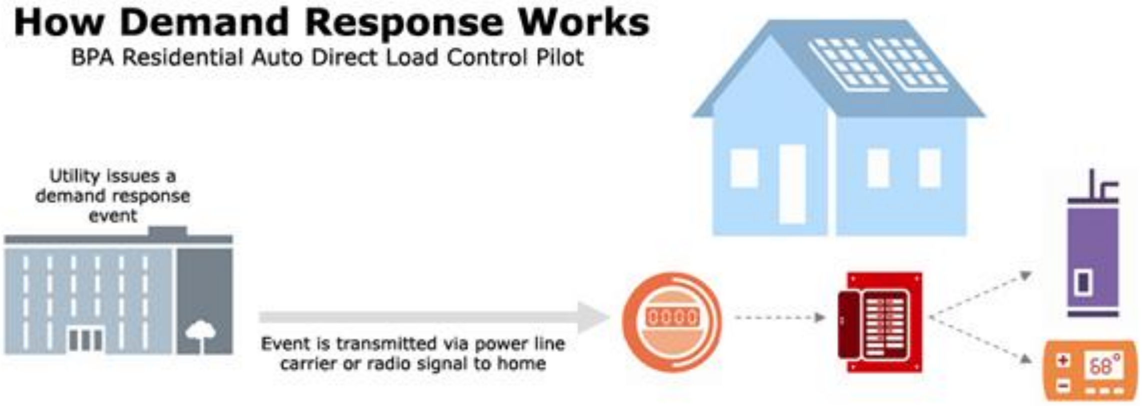


Figure 2.3 Demand Response principle [18]

The introduction of smart metering has a series of short-term and long-term benefits for the customers, energy suppliers and the network operator. A short overview of smart meter's benefits for the customer is given in the table (Table 1). These benefits have to be thoroughly explained to the customers via various educational programmes and media who have incalculable effect on the public.

Table 1 Overview of customer benefits from smart metering

Customer benefits		
Short term	Energy savings as a result of improved information	Variable pricing schemes
	More frequent and accurate billing	Better customer service
Long term	Simplification of payments for distributed generation output	Additional payments for wider system benefits
	More reliable energy supply and reduced customer complaints	Facilitating adoption of home area automation for more comfortable life

2.2. Comparison of today's grid and Smart Grid

Today's electric grid was constructed to operate as a vertical structure that consists of generation, transmission, distribution and consumers, and where only one-way power flow is present - from bulk generation to consumers. Even though the electrical power system is unique to each utility company due to economical, political and geographic factors, the basic topology is the same for all (Figure 2.4, [74]). As Figure 2.4 demonstrates, the system is strictly hierarchical and the source has no real-time information about the parameters of the termination points so it is designed to withstand the maximum anticipated peak demand.

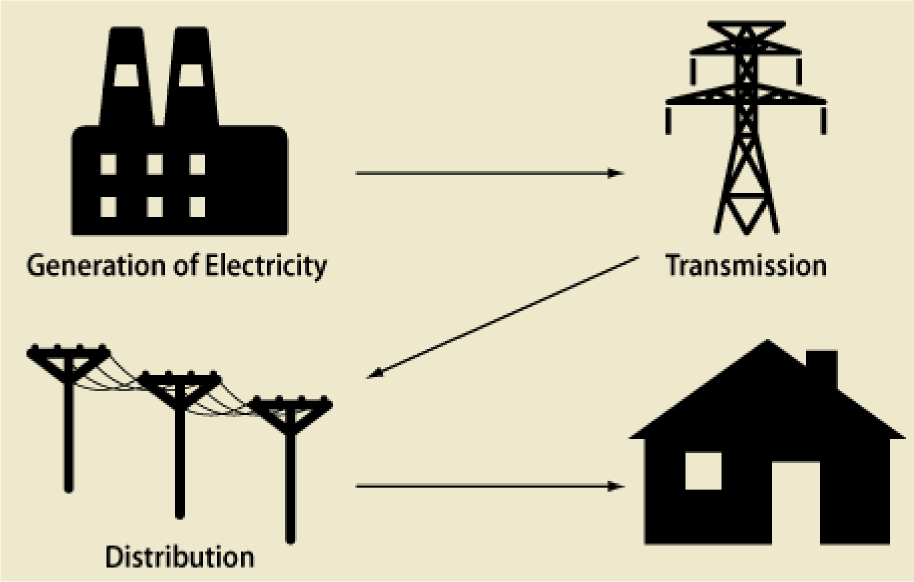


Figure 2.4 Topology of conventional power grid [74]

On the contrary, Smart Grid enables two-way communication and power flow. This gives a possibility to the consumers of becoming active members who can produce energy at the same time as they consume it. So, they are no longer called the consumers but are given a new name - prosumers. However, there must be some control from the utility so that this bidirectional flow does not occur in a hazardous manner which means that it must be known if the energy is coming from or into the house. At the same time it must be with the consumer's consent because at no circumstances should the preferences and the comfort of the consumer be compromised.

The comparison of today’s grid and Smart Grid is given in the table (Table 2). The table gives an overview of the characteristics classified into several categories. The key feature is integrating communication network that will allow bidirectional flow of information. By this, every user of the power grid will have necessary information: from the power system operator for maintaining a stable system to the homeowner for the consumption or sale of stored energy.

Table 2 Comparison of today's electric grid and Smart Grid

CATEGORY	TODAY’S GRID	SMART GRID
Consumers	Consumers don’t participate actively	Informed and involved consumers (demand response and distributed energy resources)

Accommodation of generation and storage	Dominated by central generation	Many distributed energy resources with plug-and-play convenience
Markets	Poorly integrated wholesale markets; limited opportunities for consumers	Well-integrated wholesale markets; new electricity markets for consumers
Power quality	Focus on outages	Variety of quality/price options
Optimization of assets	Little integration of operational data with asset management	Expanded data acquisition of grid parameters; focus on prevention
Anticipation of responses to system disturbances	Protecting assets following the fault	Focus on prevention and minimizing the impact to consumers
Resiliency against cyber attacks and natural disasters	Vulnerable to terrorism and natural disasters	Resilient to cyber attacks and natural disasters

2.2.1. Possible evolution of existing cities to smart cities

The Smart City is defined as a city that continually increases its performance in satisfying all needs of its citizens [20]. It must not be viewed as a sum of different parts but as a network of interconnected infrastructures dependent on each other. The essential infrastructures can be debated but they are usually narrowed down to water and energy, communication, transport and city services. Energy use is responsible for 75% of greenhouse gases emissions [20] so the smart city has to increase its energy efficiency and decrease total energy consumption. As it has already been said, Smart Grid is a concept that combines existing electrical grid and ICT. To facilitate the development of that energy-efficient and reliable system as well as the evolution of existing cities to smart form, it is necessary to continuously conduct the actions listed below:

- Identification and lowering of unreasonable barriers for adoption of Smart Grid;
- Provision to consumers of timely information and control options;
- Increased use of digital ICT to improve reliability, security and efficiency;
- Development and implementation of demand response and demand-side resources;
- Deployment and integration of advanced electricity storage and peak-shaving technologies, including integration of plug-in electric vehicles;

- Deployment and integration of distributed resources, including renewable resources;
- Integration of smart appliances; and
- Development of standards for communication and interoperability of equipment.

To fulfil different requirements of the Smart Grid, the following technologies must be developed and implemented: information and communication technology; sensing, measurement, control and automation technologies; power electronics and energy storage. In the table (Table 3 [6, 21]) is given a short overview of needed technologies in different application areas. The self-healing system should be based on a wide-monitoring network that incorporates variety of sensors, integrated power electronics as fundamental converter systems for renewable resources and storage for load levelling. As it can be seen from Table 3, new technologies must be implemented in every area of the electric system and that is the principal reason why the process is so difficult and complicated. It would probably be easier to demolish the existing grid and build a new one from scratch; however, this is not possible as the society is so used to having electricity that it would probably collapse without it after a short period.

There are numerous challenges that have to be overcome in order to achieve the goals in terms of Smart Grid. The key challenges are [22]:

- Strengthening the grid by ensuring that there is enough transmission capacity, especially for interconnecting renewable resources;
- Developing the most efficient connections for offshore wind farms;
- Delivering the communication infrastructure that will enable millions of stakeholders to participate in the market;
- Enabling all the consumers to become active members of the system through demand response;
- Integrating intermittent generation and capturing the benefits of storage; and
- Preparing the infrastructure for plug-in electric vehicles.

The development of technology that will overcome all these barriers and implementation in each individual existing city will lead to the evolution of all the cities to smart form, and consequently the electric grid as a whole.

Table 3 Overview of needed technologies for evolution to Smart Grid

APPLICATION AREA	INFORMATION AND COMMUNICATION TECHNOLOGIES	SENSORS, CONTROL AND AUTOMATION	POWER ELECTRONICS AND ENERGY STORAGE
Industries and homes	• Open architectures for plug-and-play home appliances • Two-way communication to provide connectivity between the power system and loads • Software and hardware to enable customers to trade in energy markets and provide demand-response program • Communication that gives accurate real-time information of consumer's electricity use and other related information	• Smart appliances, controls and monitors to maximise comfort and energy savings • Smart meters to allow customers to have greater control over electricity use and enable demand side participation	• Energy storage to provide greater flexibility and reliability of the system
Transmission and distribution	• Two-way communication to provide connectivity between the power system and loads	• PMU and WAMPAC to ensure the security • Integrated sensors and automation system to provide rapid diagnosis and response to any event as well as to help relieve congestion	• UPFC to provide greater control over the power flows in AC grid • Energy storage to provide greater flexibility and reliability of the system
Generation	• Two-way communication to provide connectivity between the power system and the generation	• Control and automation system of renewable energy resources	• HVDC and FACTS to enable long distance transport and integration of renewable resources • Different power electronic supporting devices to provide efficient connection of renewables

2.2.2. Examples of existing projects for smart cities/grid

It was not long ago when the majority of people was not familiar with the term “Smart City”. Today, the situation is completely different and many initiatives involving Smart Grid and smart cities are emerging. It is impossible to enumerate all the projects with evolution of currents cities to smart form as their objective; especially considering it covers many human and technology aspects. According to Boyd Cohen smart city model can be visualised as a Smart City Wheel (Figure 2.5, [23]) divided into six categories equally important for the evolution of current cities. Taking this into account there are a few cities in Europe and the world that deviate from the others by their “intelligence”.

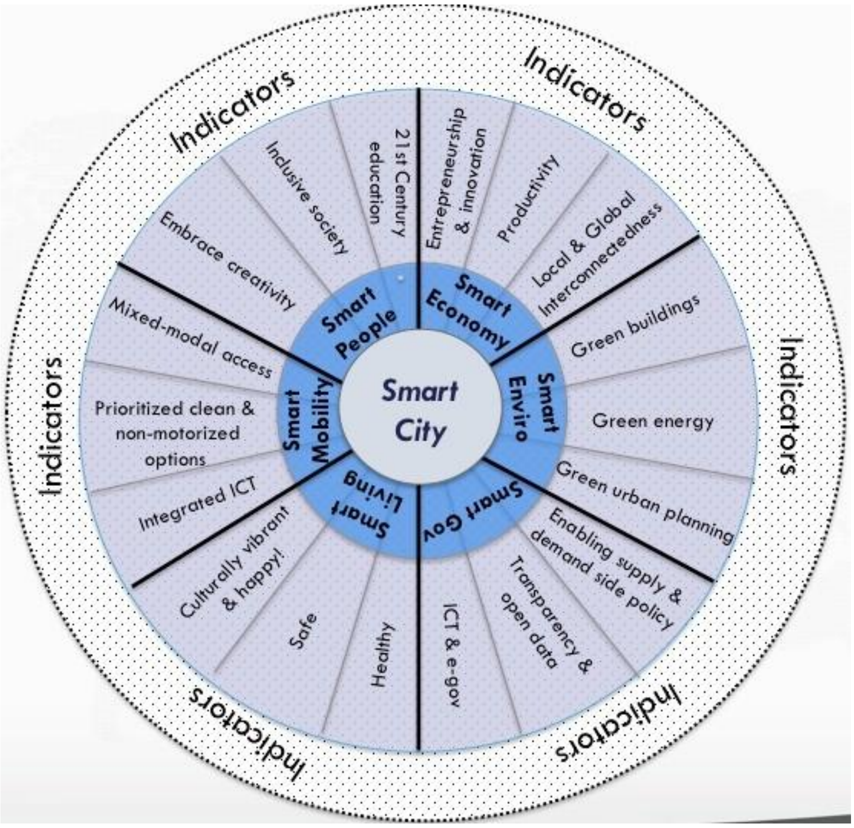


Figure 2.5 Smart City Wheel according to Boyd Cohen [23]

Vienna, Austria, is the only city ranking in the top 10 by several category lists such as innovation [24], quality of life [25] and regional green city [26]. It has established a clear vision of the city in 2050 and developed programs such as *Smart Energy Vision 2050* [27], *Roadmap 2020* [27] and *Action Plan 2012-2015* [27]. The main long-term objectives of *Smart Energy Vision 2050* are graduate reduction of ecological footprint, reduction of energy consumption and energy supply only from the renewable sources while simultaneously improving the quality of life. *Roadmap 2020* has a strategic goal of realization a smart city model district in Liesing Mitte to demonstrate the technical and economic feasibility of a smart city. The *Action Plan 2012-2015* combines over 100 individual projects falling into one of the three categories: strategic planning, demonstration projects or implementing measures. Vienna also cooperates with other smart cities in Europe such as Amsterdam, Lyon and Copenhagen.

Amsterdam, the Netherlands, is surely one of the smartest cities in Europe as it has developed a unique partnership between business, authorities, research institutions and citizens under the program Amsterdam Smart City (ASC) [44]. ASC has established 3 areas in function of living laboratories where businesses can demonstrate and test their products in 5 different themes: living, working, mobility, public facilities and open data. Currently there are 32 active projects within ASC.

Copenhagen, Denmark, must be classified into smart European cities due to its ambitious goal of carbon neutrality by 2025 [45]. This has introduced various changes in the areas of energy supply, transport and buildings through different projects such as district heating and cooling, introducing more and more wind power, and increasing the number of regular and electric bicycles. In addition, a completely new area is being developed as a sustainable city of the future that has been carbon neutral since the beginning.

In 2009, *IBM* declared that Dubuque, Iowa would become the first integrated smart city in the United States [46]. Smarter Sustainable Dubuque is a unique partnership between the City of Dubuque and IBM Research for exploring and using new smart technologies and strategies. The project is divided into 3 areas [47]: Smarter Water, Smarter Electricity and Smarter Travel which include several pilot studies such as implementation of water and electricity smart meters.

While Vienna, Amsterdam and Copenhagen are examples of transforming already existing cities into the smart form; there are some smart cities that have been created from scratch. Masdar, United Arab Emirates, is a planned city whose construction is financed by subsidiary of the Abu Dhabi Government-owned company called Mubadala Development Company (Figure 2.6, [48]). This sustainable city is designed to minimize environmental impacts, and will among other things entirely rely on renewable resources and be without conventional cars. Furthermore, it unites educational and recreational spaces with residential and business areas to provide the residents with everything they need close at hand without the need for transportation. Masdar project was launched in 2006 and was intended to be completed in 2016 [49]. However, due to the economic crisis this date is expected somewhere between 2020 and 2025. The first buildings were occupied in 2010, and the total expected population of the city is 40.000 residents and 50.000 commuters.

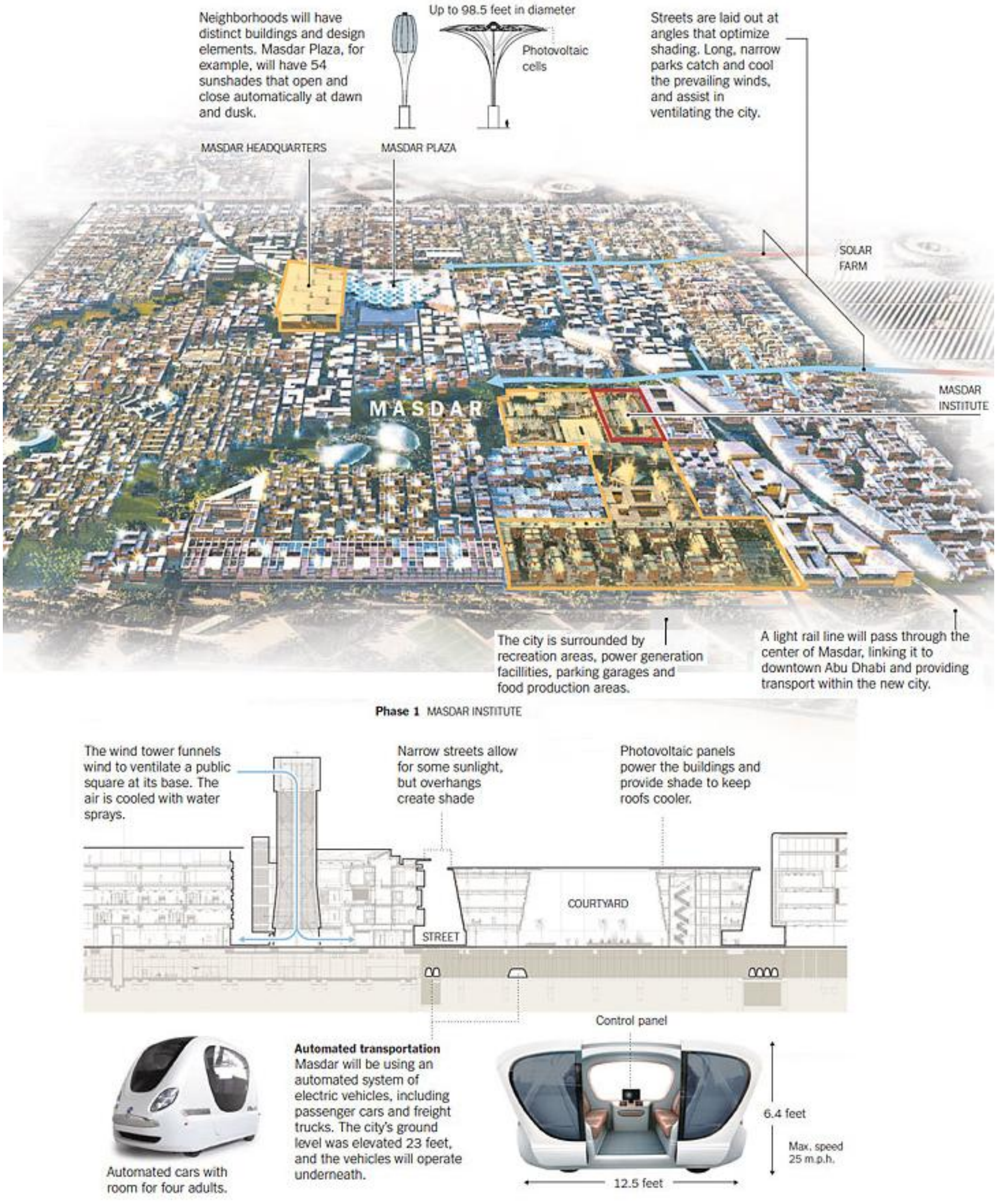


Figure 2.6 Planning the Masdar City [48]

Except for Masdar City, there are various other planned smart cities of which one is Songdo in South Korea (Figure 2.7, [50]). The design of this city has been inspired by some of the greatest cities in the world such as New York and Paris. Its commitment to sustainability is divided into 6 categories [50]: open space, transportation, water, energy use, recycling and operations. The city is fully covered with Cisco fibre optic broadband, TelePresence screens are installed in all homes, offices and public places, and additionally sensors are embedded into streets and buildings [51]. After the expected completion in 2016, Songdo will have had a total population of 65.000 residents and 300.000 commuters.

Figure 2.7 Design of Songdo's residential area [50]

A prototype of Smart Grid is also being developed in Europe under the project *EcoGrid EU* funded by the European Union [52]. The EcoGrid EU market concept is fully tested on the Danish island of Bornholm which is integrated into the Nordic power market system and where the share of renewable resources exceeds 50%. The system comprises around 26.000 electricity customers with 55 MW peak load, 36 MW of wind power, 16 MW of Combined Heat and Power, active demand, 2 MW of photo voltaic, electric vehicles and electricity storage (Figure 2.8). The EcoGrid real-time market will be an integrated part of current power markets that supports 5 minutes real-time price response.

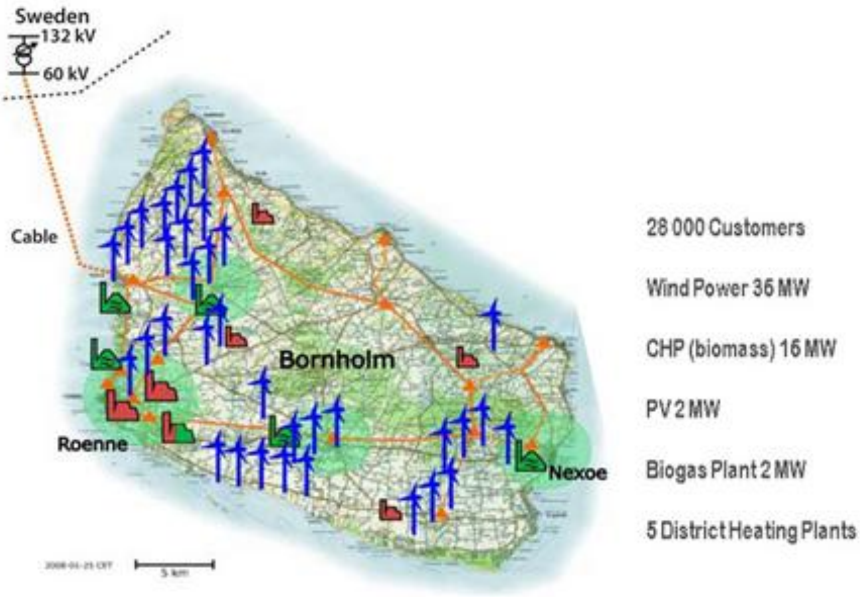


Figure 2.8 Appearance of the EcoGrid EU Smart Grid prototype

EcoGrid also strongly focuses on customer outreach and education for successful managing of Smart Grid hype cycle (Figure 2.9, [53]). As it is seen from the picture, the goal is to decrease the trough of disillusionment and quicken the return to the productivity state.

Figure 2.9 Managing the Smart Grid hype cycle

3. Smart building as the focus point

Existing cities occupy only 2% of Earth's surface yet produce over 70% of greenhouse emissions [20] and the majority of emissions come from buildings. In addition, the building sector is responsible for 40% of total energy consumption worldwide [28] so no wonder there is an increasing interest in improving and transforming them to a sustainable form. Furthermore, there is a possibility for huge financial savings considering that as much as 20% of total generation capacity is used only for 5% [29] of time which can be reduced by implementing demand response. A simplified breakdown of energy end-use in households of EU member-states is given in the figure (Figure 3.1, [30]).

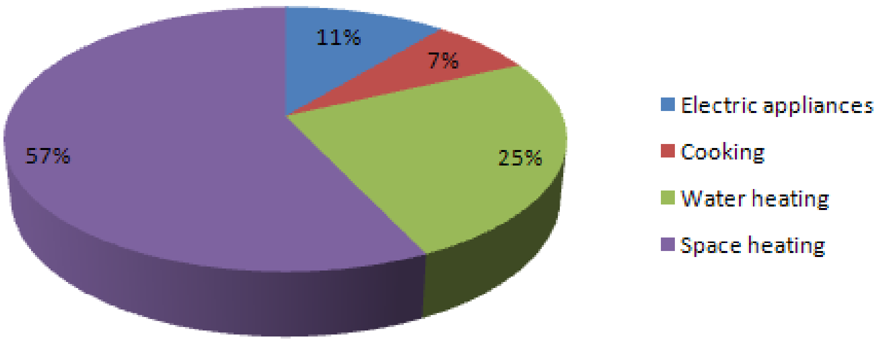
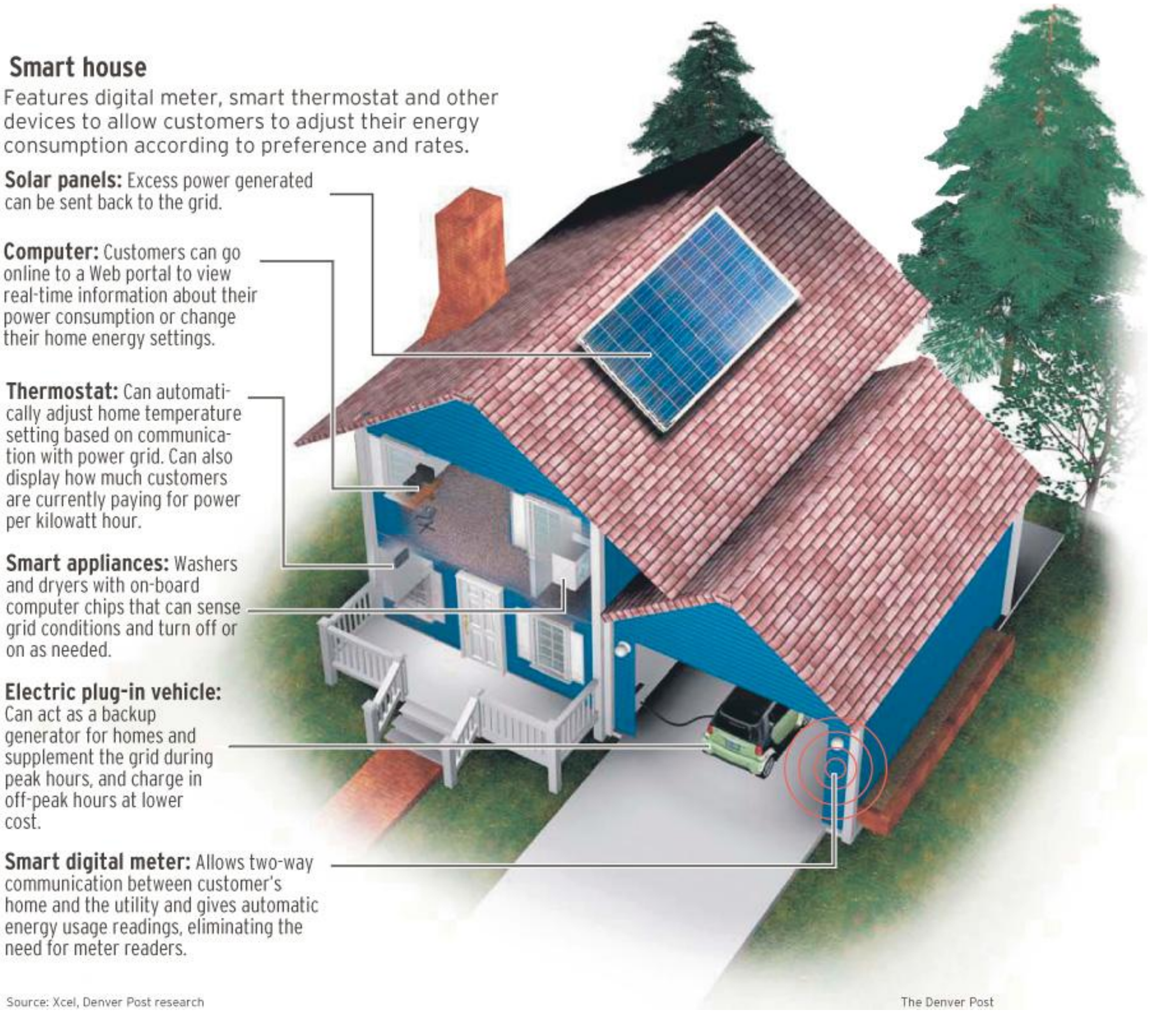


Figure 3.1 Energy use in EU households [30]

The term "intelligent building" was first used in the United States in the early 80's and it defined as a building that integrates various systems to maximise technical performance, investment and operating cost savings, and flexibility [31]. Smart building was a building that used a concept of energy efficiency and that could have been controlled from a personal computer. Although intelligence is an ambiguous term when talking about man-made systems, it is widely accepted that it refers to objects that react correctly to unforeseen circumstances. Today, the term "smart building" integrates all the features defined in the previous decades and combines them with additional systems for controlling renewable resources, energy storage and house appliances using wireless or other way of communication. Until recently, almost all devices in the house were working separately. However, today, due to development of communication technology, all the devices can communicate within themselves as well as with the grid, and thus increase consumer’s comfort and ease of use.

Every smart building has its one Building Energy Management System (BEMS) that consists of two basic parts: Building Automation System (BAS) and Telecommunications System (TS). The typical centralized BEMS has a central unit and a number of outstations which have sensors, actuators and controllers. Except for aforementioned components, the smart building contains renewable resource, energy storage and user interface. General overview of a smart building is given in the figure (Figure 3.2, [32]). Each of the elements is described in details in the following subchapters.



Smart house

Features digital meter, smart thermostat and other devices to allow customers to adjust their energy consumption according to preference and rates.

Solar panels: Excess power generated can be sent back to the grid.

Computer: Customers can go online to a Web portal to view real-time information about their power consumption or change their home energy settings.

Thermostat: Can automatically adjust home temperature setting based on communication with power grid. Can also display how much customers are currently paying for power per kilowatt hour.

Smart appliances: Washers and dryers with on-board computer chips that can sense grid conditions and turn off or on as needed.

Electric plug-in vehicle: Can act as a backup generator for homes and supplement the grid during peak hours, and charge in off-peak hours at lower cost.

Smart digital meter: Allows two-way communication between customer's home and the utility and gives automatic energy usage readings, eliminating the need for meter readers.

Source: Xcel, Denver Post research

The Denver Post

Figure 3.2 Basic parts of the smart house [32]

3.1. Basic parts of the smart building

3.1.1. Renewable resources

The micro-renewable resources are small rating energy sources located at the point of end-user, usually rooftop solar photovoltaic or a wind turbine with rated power up to 1kW. They are a part of distributed generation and provide the ability for consumers to produce their own electrical energy (Figure 3.3, [33]).

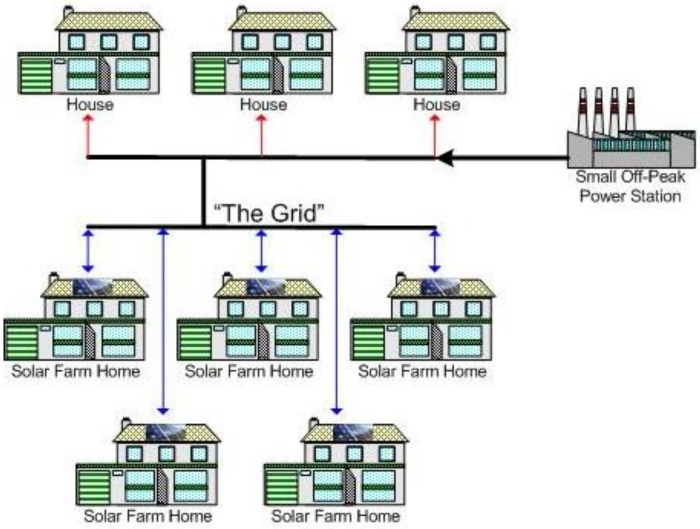


Figure 3.3 Distributed power generation [33]

In combination with energy storage, the electricity gained from renewable resources can be transformed to mechanical or electrochemical form so that it can be used in times when there is no sun or wind. Additionally, the customer has the possibility to sell the energy back to the grid in times of high electricity price, thus helping to maintain the stability of the system and at the same time making profit.

Distributed generation from renewable resources has numerous benefits for the consumer and the grid itself. Except for meeting a part of the consumption, it has a positive effect on the voltage conditions as well as power losses in the low-voltage distribution grid [34]. This can be explained by the fact that there is a less need for energy from the distribution network as the renewable resource directly supplies part of the consumption, thus leading to lower load of the lines.

3.1.2. Sensors and actuators

Within the smart house there are a number of sensors that track movement or monitor certain parameters such as temperature or humidity. They can also be used for detection of main causes of disaster: fire, flooding, gas leaks and similar. These sensors must be reliable, have low installation costs and battery consumption, and transfer real-time information via wireless communication. Today, numerous sensors for home automation already exist, from occupancy and monitoring sensors to environmental and alert sensors. Some examples of smart sensors are shown in the picture (Figure 3.4, [35-37]).

Figure 3.4 a) General Electric 45132 Choice-Alert Wireless Motion Sensor [35]; b) Smarthome MT400 Water Leak Detection Alarm [36]; c) HomeSeer HSM100 Z-Wave Multi-Sensor [37]

Apart from the sensors, the second important part of the home automation system are the actuators. These are mechanical devices that control different systems (e.g. opening or closing the windows) based on the measured parameters from the sensors or direct user command. Smart actuators are usually manipulated by the central unit through the controllers.

3.1.3. Controllers

Controllers are units that control the processes inside the smart building by wired or wireless mean, depending on how they are programmed by the user. They contain input ports through which they have access to sensors’ data and output ports through which they send control signals to their slave devices. All of the controllers are connected to the central unit which communicates with the smart meter.

3.1.4. Central unit

The central unit is the core of the home automation system as it manages all the controllers in the smart building. It is used for reprogramming, maintenance and changes in the system after the initial programming of the controllers. Furthermore, it allows the user to add more devices and program them according to his predispositions.

Some of the controllers are supplied with their own central unit while others use a PC as a server with additional software. On the other hand, as the controllers have a processor on their own, in principle, it is not necessary to have a central unit to manage them. However, this is not usual in practice due to the simplicity of reprogramming the controllers from one place.

3.1.5. Smart meter

Traditional meters are used to measure the quantity of electricity supplied to the consumer. They are usually accumulation meters that record energy consumption over time and must be read manually. These meters were widespread prior to the year 2000 after which Automatic Meter Reading or meters with one-way communication were developed. AMRs are capable of sending consumption information to the utility, usually once a month, and allow the customer to understand and manage their pattern of electricity demand. The logical extension of these meters are smart meters which are more sophisticated as they have two-way communication allowing interactivity between the utility and the consumer. Evolution of electricity metering is shown in the figure (Figure 3.5).

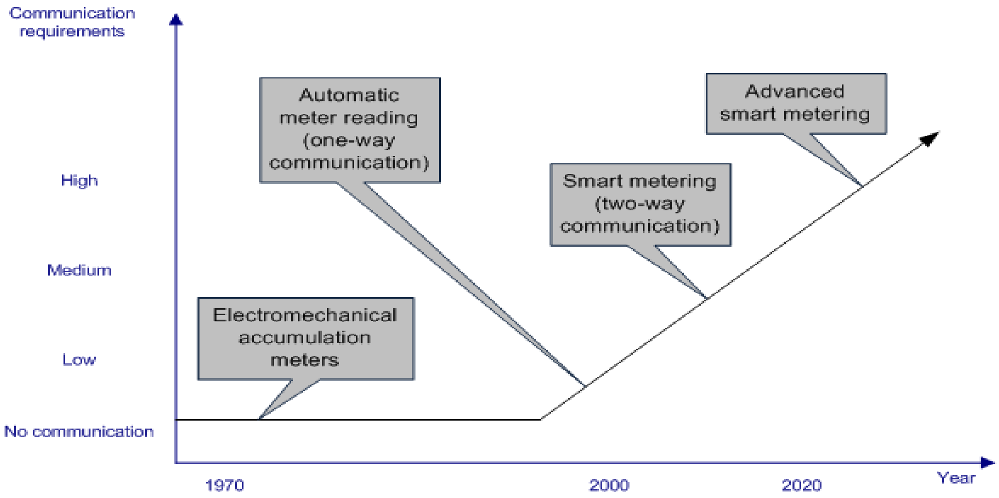


Figure 3.5 Evolution of electricity metering

This Advanced Metering Infrastructure (AMI) includes smart water, gas, electricity and heat meters. However, in terms of this paper, it refers to a smart electricity meter (Figure 3.6, [38]).

Figure 3.6 Smart electricity meter [38]

The smart electricity meter has several characteristics:

- Real-time measurement of electricity consumption and local generation;
- Can be read remotely and locally;
- Limiting the consumption based on income signals from the utility;
- Receiving price signals from utility and allowing customer to respond to them; and
- Communication with the central unit for controlling total consumption.

Basic idea of the smart meter is to serve as a communication gateway allowing demand response program, i.e. adjustment of the consumption in accordance to utility's wishes. Of course, this is done in exchange for other benefits for the consumer, e.g. lower electricity price. Demand response principles and services provided by it will be explained in separate subchapter.

3.1.6. Smart end-use devices

Smart appliances are end-use devices such as refrigerators, air conditioners, washers and many more that respond to signals sent by the central unit. They are designed to effectively reduce domestic usage of energy and consequently lead to smaller electricity bills and impact on the environment. Traditional appliances are passive units that can not be controlled or programmed. On the contrary, new smart appliances react to certain signals and postpone their activation for the period when it is more suitable for the grid. However, even the conventional passive appliances can be turned into smart appliances by adding an actuator on it.

Use of household appliances in several European countries based on survey supported by the European Commission is given in the table (Table 4, [15]).

Table 4 Use of household appliances in EU countries [15]

Household appliance	Austria	Germany	Italy	Slovenia	UK
Washing machine	97 %	100 %	98 %	100 %	98 %
Refrigerator	98 %	100 %	99 %	99 %	98 %
Deep freezer	81 %	91 %	57 %	77 %	71 %
Dishwasher	81 %	95 %	58 %	61 %	40 %
Electric cooker	93 %	98 %	33 %	43 %	65 %
Tumble dryer	30 %	76 %	7 %	34 %	42 %
Electric heated boiler (80 l)	16 %	22 %	8 %	37 %	8 %
Electric water heater (10 l)	10 %	10 %	14 %	20 %	14 %
Electric space heater	3 %	20%	9 %	15 %	13 %
Air conditioner	1 %	6 %	27 %	18 %	1 %

The mentioned appliances will evolve into the smart form and they will have two modes of operation according to user’s preferences:

1) Mode A: The user receives information via a display on the appliance that it would be better to start operation at a specific time later that day. The user decides whether to wait with the operation or not; and

2) Mode B: The appliance is set to “smart mode”. During operation short interruptions might occur and the operation might be prolonged.

These modes allow the customer to choose mode A if he wants the operation to be executed at that precise moment or mode B if he is indifferent to time of execution. By choosing the desired mode, customer’s comfort is never compromised. Some smart appliances are shown in the figure (Figure 3.7, [39]).

Refrigerator
This Profile refrigerator can reduce energy use on demand and delay defrosts to inexpensive rate periods.

Range & Microwave
Cooking energy is reduced and with dual cavities, the range can preference the smaller upper oven.

Dishwasher
The dishwasher is aware of expensive rate periods and can wait to run when energy costs are lower.

Laundry Pair
When high rates arise, this laundry pair will save you money while getting your clothes clean and dry.

Hybrid Water Heater
The water heater can switch to heat-pump mode and modify temperature settings during high rates.

Figure 3.7 Smart appliances in a smart house [39]

3.1.7. Energy storage

Energy storage facilities can be used for both the production and the consumption. Support for renewable energy, electrical energy shifting and load scheduling requires a great amount of energy and a discharge duration of several minutes to hours. This is not possible without energy storage due to the nature of electrical energy which has to be consumed at the same time when it is produced.

The basic principle for the customer is rather simple: buy electricity when it is cheap and sell it when it is expensive. This is based on expected electricity prices on the spot-market that are known and reasonably predicted a few days ahead. Furthermore, the customer has a full range of revenue opportunities. Distributed energy storage can be used as an ancillary service that is available for discharge in times of need, thus decreasing the need for spinning reserve. In addition, it can provide voltage support for the network as well as reduction of congestion during the peak demand periods, and all this with an appropriate fee for the user. From all of the above, it is easy to conclude that the customer wants as much storage capacity as possible. However, the selection of proper storage technology is greatly influenced by the capital and operational costs as well as size, efficiency and life expectancy. Hence, the decision on the storage technology is not an easy one for the customer. The comparison of some storage technology options is given in the table (Table 5, [7, 40, 41]).

Table 5 Comparison of several storage technologies

Storage technology	Advantages	Disadvantages	Capital cost [$/kW]	Efficiency	Life cycles	Density [kWh/m³]
NaS	High density; lower maintenance costs	High operating temperatures; sodium burns in contact with air and moisture	1000-2000	87%	2000	200
Flow Battery	Unlimited storage capacity[2]	After 3-5 years the system has to be changed	700-2500	80%	2000	25
Li-Ion	Use less space than lead-acid batteries	Too expensive for large scale applications	700-1500	95%	4000	300
Ni-Cd	Tolerate deep discharge for long periods;	Cadmium is highly toxic	500-1500	60-70%	1500	50
Flywheels	Charge and discharge rapidly; lower maintenance requirements	Power loss faster than from batteries	4000-10000	93%	20000	15

3.1.8. District heating

Except for electricity, an important issue for a smart building is also heating where district heating has a noticeable role. District heating describes a system where there is a considerable distance between the place where heat is generated and the place where it is used. The system consists of 3 parts [72]:

- A generation system (power plant);
- A distribution system (underground pipes); and
- Individual heating systems at the users.

From the power plant, the heat is sent through the pipes to the heat exchanger substation from where it is distributed to the users (Figure 3.8, [73]). This kind of heating is ideal for space

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[2] Only limitation is the size of electrolyte storage

heating as the supply water can be used directly after which it is returned to the district heating plant. Also, through the heat exchangers, the supply water transfers its heat to domestic hot water and reduces the need for electric water heaters.

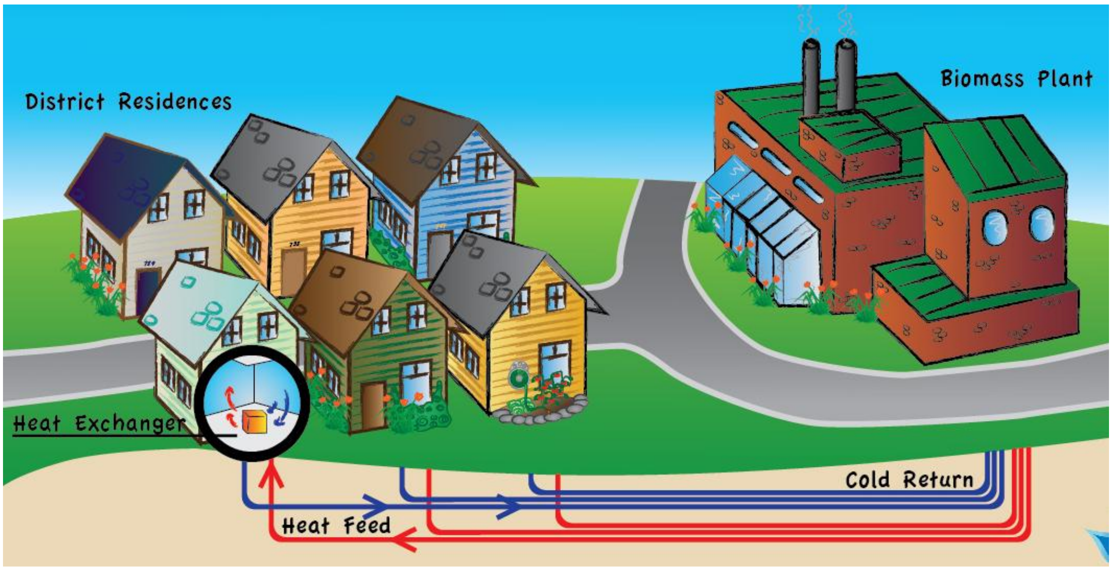

Figure 3.8 Principle of district heating [73]

District heating plants are usually combined heat and power plants that can be driven by various energy sources including biomass, solar energy and waste. These kinds of plants are better at reducing emissions compared to individual heating systems due to controlled and optimised heat generation which makes them more environmentally friendly. Furthermore, they are more energy efficient due to simultaneous production of heat and electricity. However, district heating has several disadvantages such as relatively high heat losses because of long distance distribution system and non favourability for areas with small population density.

3.1.9. Communication network

Proper functioning of a smart building is not possible without a communication network which enables communication between different devices within the building as well as communication to the external grid. As mentioned before, a huge amount of confidential data is transferred between the utility and smart meter, thus communication technologies to be chosen must have better security features. In addition, the network has to fulfil several other requirements such as good transmittable range, power quality and cost efficiency.

Home Area Network (HAN) is a type of Local Area Network (LAN) restricted to an individual building. Its architectural structure enables access to all data and messages by all connected devices. Messages are control signals that come from the central unit and contain the addresses of one or several devices to whom they are intended for. The devices react only to the messages with their own addresses or corresponding group, e.g. shutting down one lamp in the room or all of them.

Some of the technologies that can be possibly used for the HAN are [42]:

- ZigBee – wireless mesh networking based on IEEE 802.15.4 media standard where at least two pathways connect each node; connections are dynamically updated and optimised;
- Wi-Fi – popular wireless technology based on mature IEEE 802.11 standards;
- Ethernet – very common communication technology that uses copper “twisted-pair” cabling or fibre optics;
- Z-Wave – wireless communication designed specifically to remote control applications in residential buildings; restricted to Zensys[3] customers;
- Home Plug – power line communication technology that uses existing electricity wiring to communicate; and
- Wireless M-bus – radio variant of meter bus which is an European standard for remote reading of gas or electricity meters.

3.1.10. User interface

User interface allows the customer to communicate with the system. Through it, the user can set his predispositions and levels of automatic control over the system. The interface has to be intuitive and user-friendly.

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[3] a company located in California; designer and promoter of the Z-Wave standard wireless sensor network for home automation

3.2. Demand response and dynamic pricing

There are various terms in use in demand side whose meanings are closely related but slightly different. Therefore it is necessary to distinct two broadly used terms: demand side management (DSM) and demand response (DR).

In demand side management the utility monitors and controls the loads once the customer gives his consent. It is an effective means of modifying customer demand in order to reduce operating costs where the power company chooses the operation mode for the appliances and the customer has no control of when and how long the appliances will operate. Demand side resources such as smart appliances, distributed generation and energy storage can provide various services to the power system. The most common ones are load shifting where the consumption is shifted to off-peak time, valley filling where the off-peak demand is increased through storing energy, and peak clipping which reduces the peak load demand (Figure 3.9, [7]).

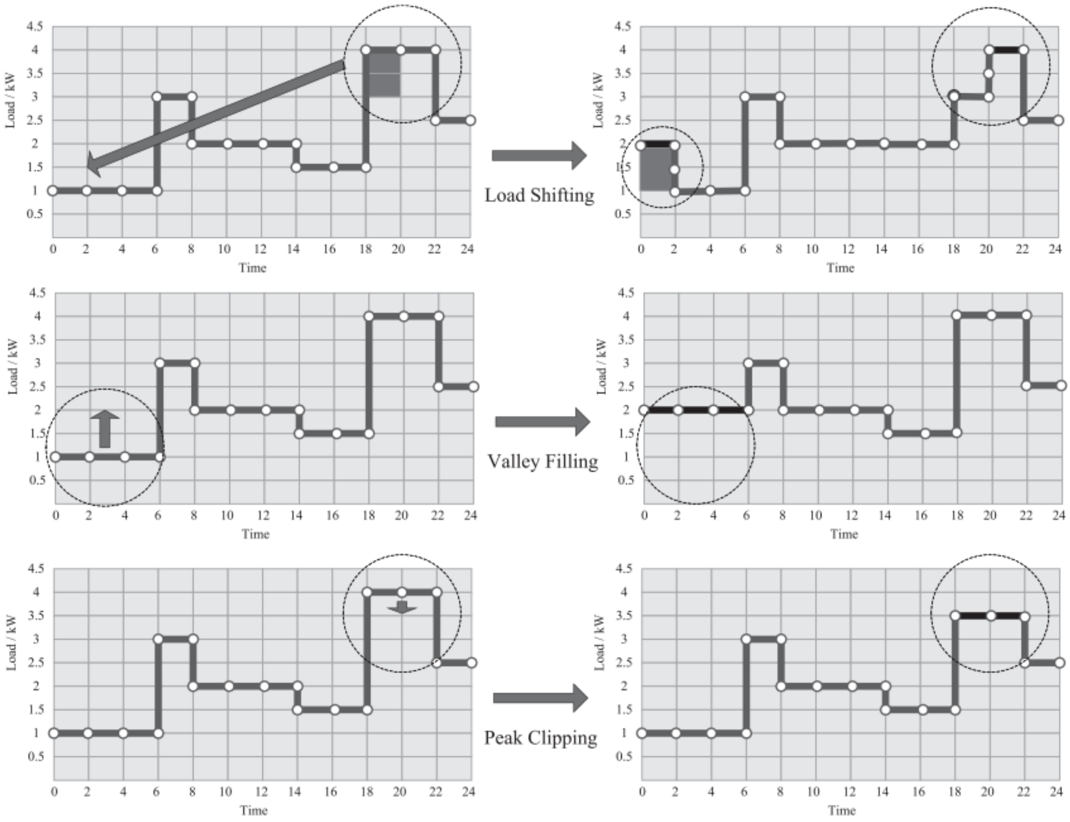


Figure 3.9 Different DSM services [7]

On the contrary, DR inherits the characteristics of DSM but gives full control to the customer who can decide what load to control based on the signals they get and personal preferences. The implementations of demand response programs are classified in two categories: price-based and incentive-based. Tariffs and pricing can be an effective means to influence customer behaviour so the basis of price-based implementation is customer's load change in response to electricity price. On the other hand, the incentive-based DR gives the customer different incentives that are separated from electricity price and added to the retail electricity rates. List of various kinds of price-based and incentive-based DR implementations is given in the table (Table 6, [7]).

Table 6 Overview of DR implementations

Implementation	Description
Price-based implementation	
Time of use (ToU)	Different unit prices for different time blocks; usually predefined for a 24-hour day
Real-time pricing (RTP)	The electricity price fluctuates hourly reflecting changes in the wholesale electricity price; customers notified on day-ahead or hour-ahead basis
Critical peak pricing (CPP)	Hybrid design of ToU and RTP; the basic rate structure is ToU with normal peak price replaced by much higher price
Incentive-based implementation	
Direct load control	Electrical appliances are controlled remotely by the utility on short notice
Interruptible/curtailable service	Curtailment options integrated in retail tariffs in exchange of demand reduction during system contingencies; possible penalties for failing to curtail
Demand-side bidding	Customers offer bids for curtailment based on wholesale electricity prices
Emergency DR programs	Incentive payments to customers for demand reduction in times of short system reserve
Ancillary service market programs	Customer bids load curtailments as operational reserves; if accepted, they are paid the market price for standby mode

With the deployment of smart metering and two-way communication, the customer is encouraged to participate in electricity market by responding to market prices. The DR program allows the customer to sell energy services either in form of demand reduction or in form of local generation. It requires prices that vary in time, also known as “dynamic prices”, as well as customer’s awareness of price variations and manual or automatic adaption to them. Real-time pricing is very effective in shaping and flattening the total demand curve. Assuming the utility is regulated and its objective is to maximise social welfare with addition of customer’s wish to maximise its own benefit, the equilibrium of generation and demand is found in the market. Many simulation models have been made to analyse load behaviour under various DR schemes. The results for electricity DR for one of the models are given in the figure (Figure 3.10, [43]). It is clear that different appliances are coordinated by electricity price to flatten power demand at different time of the day. With introduction of real-time pricing, greater improvements in eliminating peak hours are visible. Furthermore, the energy storage additionally reduces the variation in power demand consequently increasing the load factor and providing larger savings in generation cost.

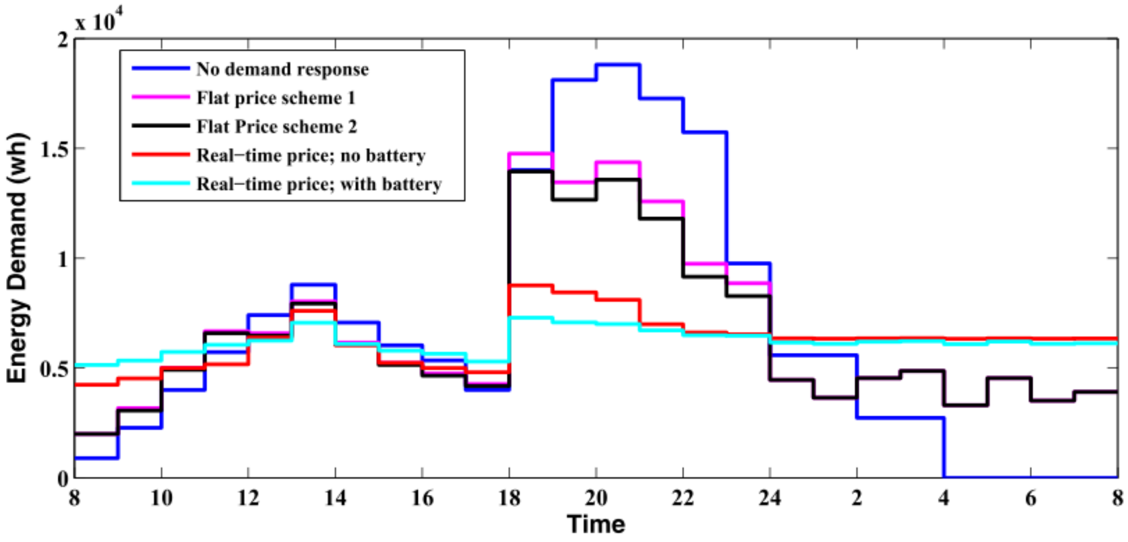


Figure 3.10 Demand curve for various DR schemes [43]

4. Model of a smart house

The basic features and functionality of a smart house will be shown using a draft model developed in the program AnyLogic which uses graphical modelling language extended with programming language Java. Based on this model, several scenarios will be simulated in order to demonstrate the behaviour of a smart house in different situations such as (non)availability of solar resources, load decrease signal from the grid and increase in electricity market price.

4.1. Model description

The simulation model of a smart house has been implemented as a dynamic system because of several parameters that change in time, such as electricity taken from the grid. The smart house itself has been realised as a program agent which provides the possibility to extend the model with a number of smart houses, each one of them based on the fundamental program agent in addition with some modifications.

The model consists of a program agent (smart house), behaviour algorithm and the environment in which the agent is placed. This has been realised at two levels – level of the smart house with smart appliances and level of the environment in which several parameters crucial for the functioning of the house can be changed. Furthermore, the level of the environment provides insight in the total electricity taken from the grid and the state of smart appliances in the house.

4.2. Level of the smart house

First level of the simulation model is the level of the smart house (Figure 4.1). At this level, there are several features of the smart house: manageable and unmanageable appliances, micro-renewable resource, micro energy storage and smart meter with energy management system that communicates with the power grid. Features will be described in more details in the following subchapters.

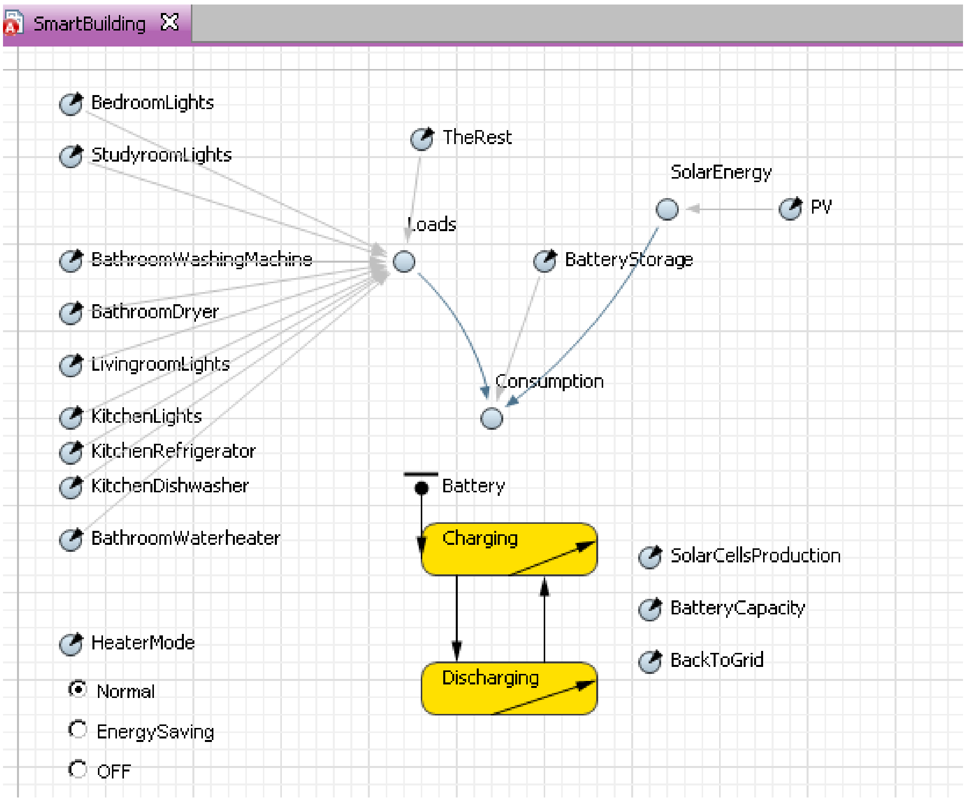


Figure 4.1 Level of the smart building in AnyLogic

4.2.1. PV as a renewable resource

Photovoltaics have been chosen as a micro-renewable resource due to the assumption that the installation and connection to the grid of this resource are the simplest and the most convenient for the user. It is expected that every smart house in the future will have PV as a distributed resource.

The nominal power of the PV in this model is 5 kW which is enough to power the whole consumption of the house. The surplus of energy is sold back to the grid. Production curve for the PV depends on several conditions among which the most important one is weather, more precisely if it is sunny, partly cloudy or a rainy day. In the case of partly cloudy weather, the production of PV is 50% of that on a sunny day [54]. Of course, in the case of a rainy day, there is no production from the renewable resource. Daily production curve in dependence of the weather that is used in this model is shown in the figure (Figure 4.2).

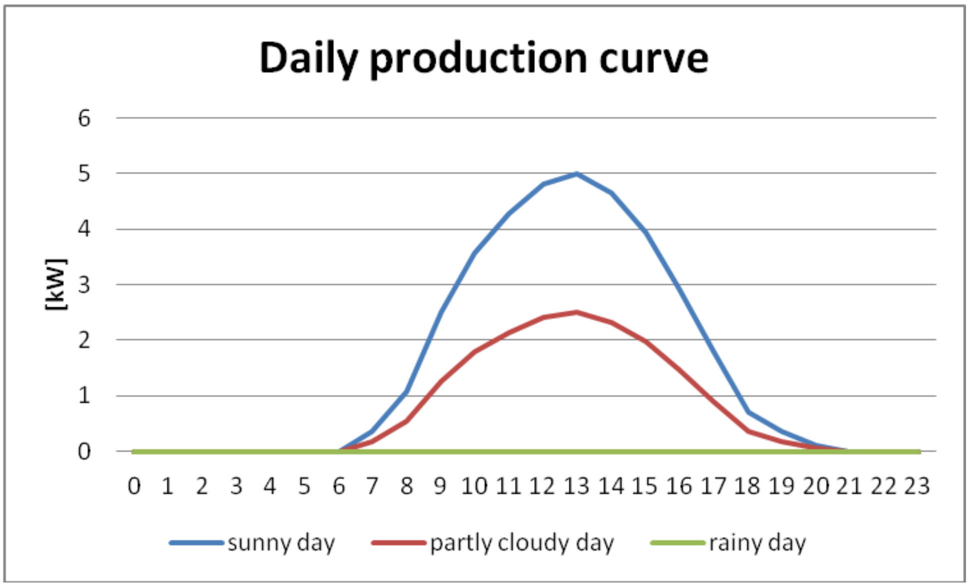


Figure 4.2 Daily PV production curve

4.2.2. Micro energy storage

Micro energy storage in the model is a battery of 9 kWh, which has been chosen due to a case study where several houses were equipped with these kinds of batteries [40]. The storage is modelled in two states: charging and discharging (Figure 4.3).

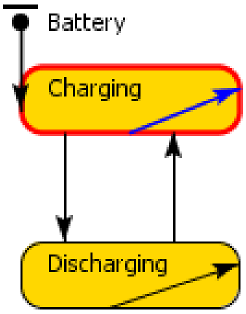


Figure 4.3 Battery states modelled in AnyLogic

The charging takes place if there is energy available from the solar cells as well as if the total consumption of the loads multiplied with the current electricity price is lower that the set limit the customer is willing to pay. The discharging of the battery is triggered with several conditions: the maximal battery capacity is achieved, current electricity price is higher than the set price limit set by the customer and there is enough energy in the battery to supply the surplus of consumption in relation to maximal consumption the customer is willing to pay at the current price.

4.2.3. Demand side management capabilities

The smart house is equipped with several manageable smart appliances and other unmanageable appliances that have been represented as one parameter – the rest of the consumption (Figure 4.4).

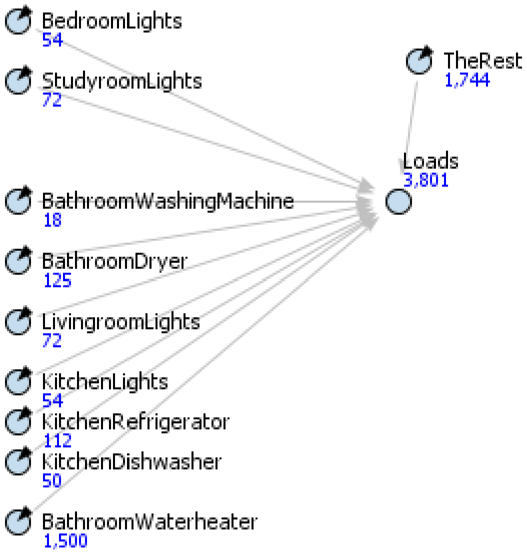


Figure 4.4 Overview of modelled appliances in a smart house

There are 9 manageable appliances in total that can partly or fully reduce their consumption in respect to load decrease signal. Demand-response implementation is incentive-based which means that the grid directly controls the loads in times of peak hours (from 8:00 to 12:00 and from 18:00 to 22:00). The controllable loads used in the model are:

- Bedroom lights – 3 compact fluorescent lights of nominal power 18 W (total 54 W) that are turned on for 5 hours in periods from 6:00 to 7:00 and from 20:00 to 23:00. The lights are 50% dimmable;
- Study room lights – 4 compact fluorescent lights of nominal power 18 W (total 72 W) that are turned on for 8 hours in the period from 18:00 to 2:00. The lights are 50% dimmable;
- Washing machine – manageable appliance with the average consumption of 18 Wh in 1 hour [55] that can be shut down at the request of the power grid;
- Clothes dryer – manageable appliance with the average consumption of 125 Wh in 1 hour [55] that can be shut down at the request of the power grid;

- Living room lights – 4 compact fluorescent lights of nominal power 18 W (total 72 W) that are turned on for 8 hours in the period from 18:00 to 2:00. The lights are 50% dimmable;
- Kitchen lights – 3 compact fluorescent lights of nominal power 18 W (total 54 W) that are turned on for 5 hours in period from 18:00 to 22:00. The lights are 50% dimmable;
- Refrigerator – manageable appliance with the average consumption of 112 Wh in 1 h (nominal power of 450 W but works in cycles 15 minutes on and 45 minutes off). It can be shut down at the request of the power grid but automatically turns on after 4 hours so that the contents would not get spoiled. The refrigerator has to be turned on at least 2 hours before switching off;
- Dishwasher – manageable appliance with the average consumption of 50 Wh in 1 hour that can be shut down at the request of the power grid; and
- Water heater – inspired by a GE smart water heater [56], the water heater in the model has two modes: normal mode with the nominal power of 1500 W and energy saving mode with the nominal power of 550 W. The choice of the mode is given to the customer. The water heater can be turned off at the request of the power grid but automatically turns on after 3 hours due to the assumption that the water cools down by 15°C in that time. Furthermore, depending on the chosen mode, the water heater will not be turned off if it has not been turned on at least 2 hours in the normal mode or respectively 4 hours in the energy saving mode in order to have enough time to heat the water.

The smart appliances have a priority list generated by the customer based on which the energy management system controls the loads. In this model, the priority list for turning off the loads has been randomly chosen and it is given in the table (Table 7). The load with priority number 1 is the least important appliance that will be turned off first, respectively the one with priority 9 will be turned off the last. Of course, the priority list for turning on the loads is the opposite.

Table 7 Priority list for controllable appliances

Controllable load	Priority
Bedroom lights	6
Study room lights	8
Washing machine	3
Clothes dryer	1
Kitchen lights	7
Refrigerator	4
Dishwasher	2
Living room lights	9
Electric water heater	5

The rest of the consumption in a smart house is represented as one parameter. A daily consumption curve is obtained for a typical Norwegian household on a work day at the temperature of 10°C in the period from March to November. The consumption is without the water heater and electric space heating (Figure 4.5).

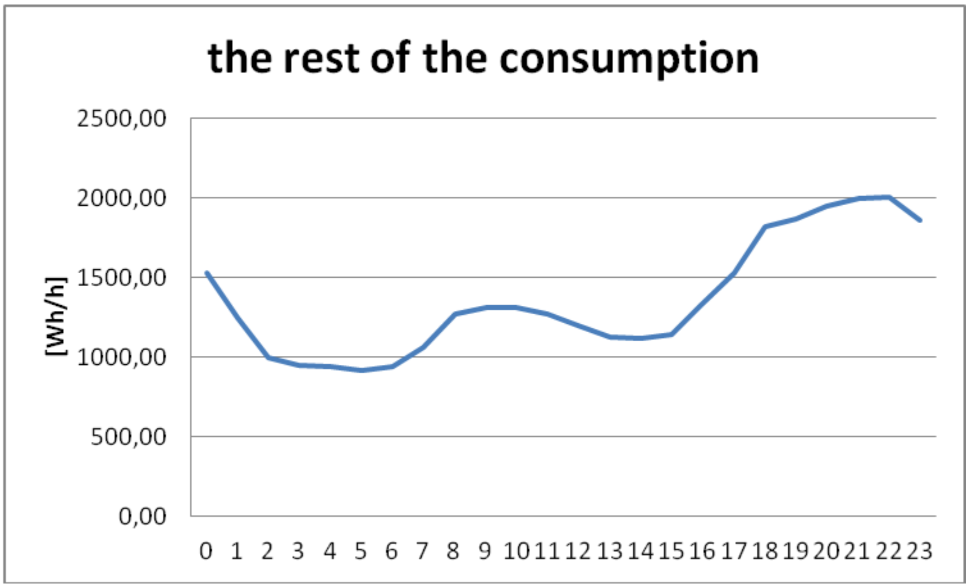


Figure 4.5 Daily curve for parameter representing the rest of the consumption

4.2.4. Basic electricity price based consumption controller

There are two price parameters in the model. The first one is market price obtained from Nordpool spot market [57] for a typical workday (Tuesday, 21st March 2013) shown in the figure (Figure 4.6). It is clear from the figure that the direct load control in peak times coincides with high electricity prices.

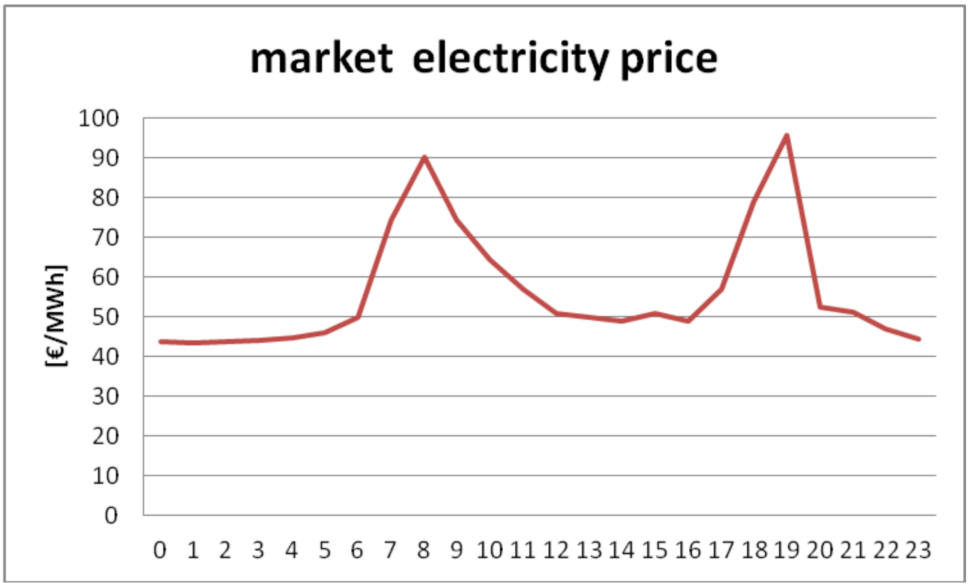
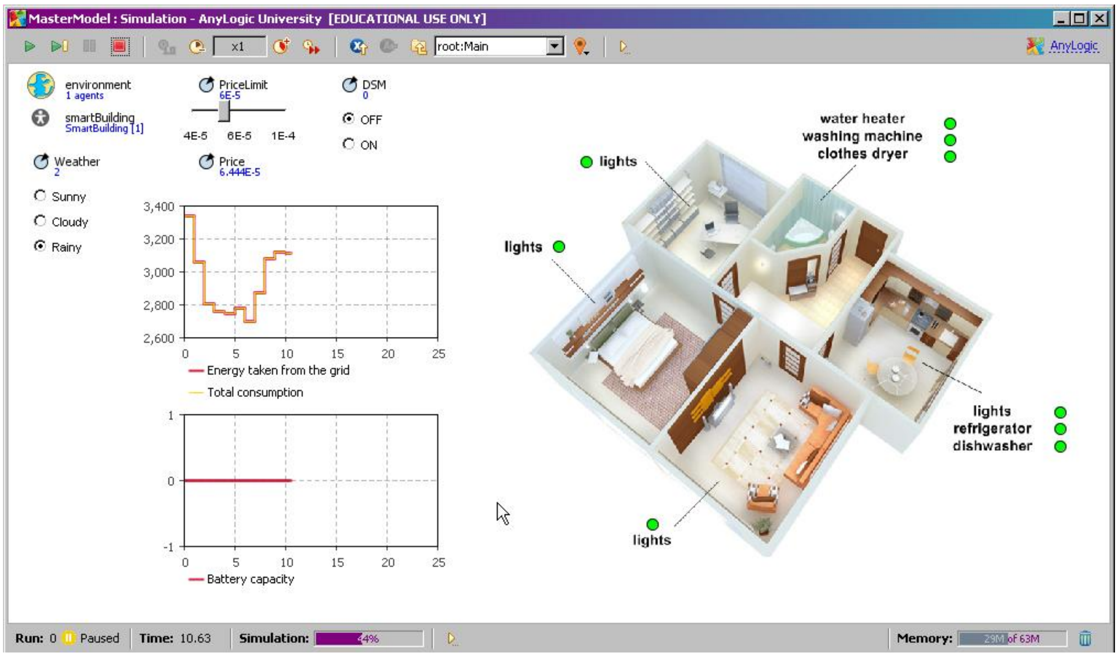


Figure 4.6 Electricity price on the Nordpool spot market on 21.3.2013.

The second price parameter is the limit the customer is willing to pay for the electricity. If the price limit is lower than the current market price, part of the consumption will be supplied from the battery storage in order to lower the energy drawn from the grid and consenquently to lower the electricity bill. The price limit can be manually changed at the level of the environment from 40 €/MWh to 100 €/MWh.

4.3. Level of the environment

The second level of the model is the level of the environment where insight is provided into the consumption of the smart house and state of the smart appliances (Figure 4.7). In the environment there are several changeable parameters such as the weather (the user can choose between sunny, cloudy and rainy weather), electricity price limit for the customer (changeable from 40 €/MWh to 100 €/MWh) and load decrease signal which represents grid’s request for lowering the consumption by turning off the smart loads in regards to the priority list.



environment 1 agents
smartBuilding SmartBuilding [1]
Weather 2
○ Sunny
○ Cloudy
● Rainy
PriceLimit 6E-5
4E-5 6E-5 1E-4
Price 6.444E-5
DSM 0
● OFF
○ ON
Run: 0 Paused | Time: 10.63 | Simulation: 4% | Memory: 29M of 63M

Figure 4.7 Level of the environment in AnyLogic

Furthermore, in the level of the environment there are several graphs that show total energy drawn from the grid, total consumption of the smart house and battery capacity. Except for insight into the consumption, it is important to know the state of the smart appliances, i.e. if they are switched off. For that purposes, there is a layout of the house with marked smart appliances (Figure 4.8). Next to every smart appliance there is a circle coloured in green, orange or red. The colour displays the state of the load: green means the load is fully operating, orange means the load is partially turned off (this is applicable only to the lights which can be dimmed by 50%) and red means the load is switched off.

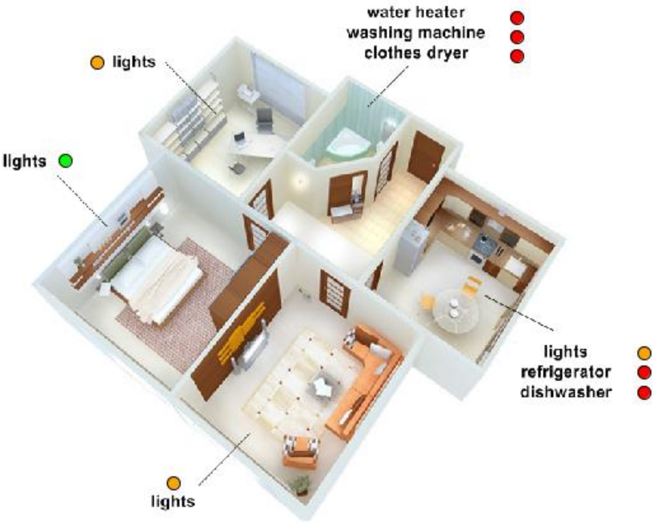


Figure 4.8 Layout of the smart house with marked smart appliances

4.4. Scenarios

To show the basic features and functionality of a smart house, several simulation scenarios have been conducted. All of the simulations are based on a 24-hour time range; more precisely they demonstrate the behaviour of a smart house during one day. The conducted simulations are:

1) The smart house is operating with full consumption without the availability of solar energy (rainy day). There is no load decrease signal from the grid and the electricity price limit is set to 100 €/MWh;
2) The smart house is operating with full consumption and available energy from the solar cells (sunny day). There is no load decrease signal from the grid and the electricity price limit is set to 100 €/MWh. Two sub-scenarios conducted: the battery was empty and the battery was full prior to the occurrence of solar energy;
3) The smart house is operating with full consumption and available energy from the solar cells (partly cloudy day). There is no load decrease signal from the grid and the electricity price limit is set to 100 €/MWh. Two sub-scenarios conducted: the battery was empty and the battery was full prior to the occurrence of solar energy;
4) The smart house is operating with full consumption without the availability of solar energy (rainy day). There is no load decrease signal from the grid and the electricity price limit is set to 60 €/MWh. Two sub-scenarios conducted: the battery was empty and the battery was full prior to the occurrence of solar energy;
5) The smart house is operating with full consumption and available energy from the solar cells (sunny day). There is no load decrease signal from the grid and the electricity price limit is set to 60 €/MWh. Two sub-scenarios conducted: the battery was empty and the battery was full prior to the occurrence of solar energy;
6) The smart house is operating with full consumption and available energy from the solar cells (partly cloudy day). There is no load decrease signal from the grid and the electricity price limit is set to 60 €/MWh. Two sub-scenarios conducted: the battery was empty and the battery was full prior to the occurrence of solar energy;

7) The smart house is operating with full consumption without the availability of solar energy (rainy day). There is a load decrease signal from the grid in two peak hour periods and the electricity price limit is set to 100 €/MWh;
8) The smart house is operating with full consumption and available energy from the solar cells (sunny day). There is a load decrease signal from the grid in two peak hour periods and the electricity price limit is set to 100 €/MWh. Two sub-scenarios conducted: the battery was empty and the battery was full prior to the occurrence of solar energy;
9) The smart house is operating with full consumption and available energy from the solar cells (partly cloudy day). There is a load decrease signal from the grid in two peak hour periods and the electricity price limit is set to 100 €/MWh. Two sub-scenarios conducted: the battery was empty and the battery was full prior to the occurrence of solar energy; and
10) The smart house is operating with full consumption and available energy from the solar cells (sunny day). There is a load decrease signal from the grid in two peak hour periods and the electricity price limit is set to 60 €/MWh.

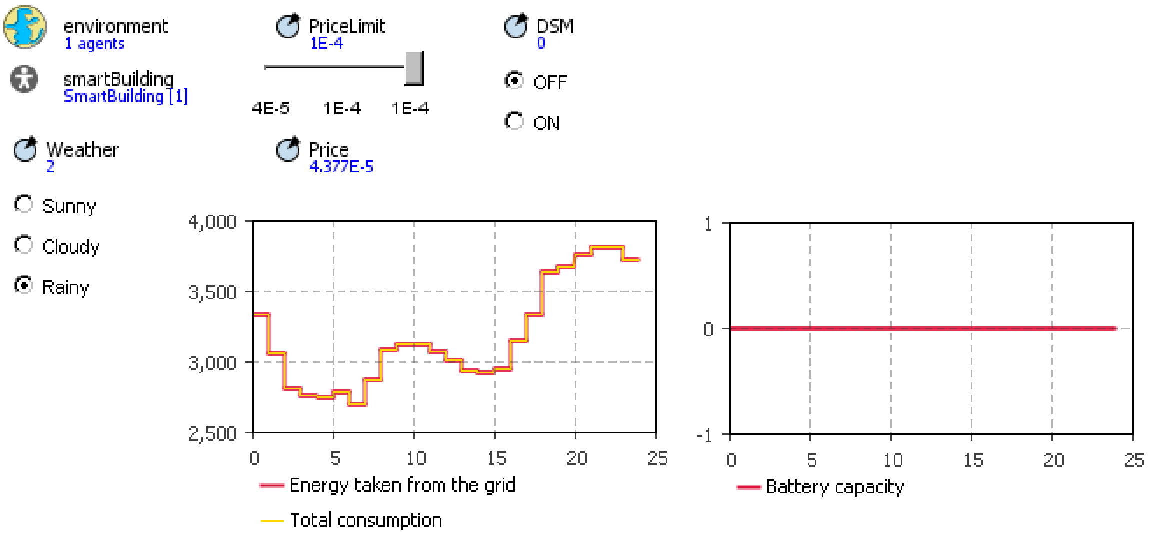
The results of the individual simulations are given in the following chapter.

5. Results

5.1. Scenario 1

The smart house is operating with full consumption without the availability of solar energy (rainy day). There is no load decrease signal from the grid and the electricity price limit is set to 100 €/MWh.

In this case, the smart house operates with all of the consumption powered from the grid which can clearly be seen from red and yellow lines overlapping (Figure 5.1). Depending on which water heater mode is chosen, the full consumption differs. Figure 5.1 shows the consumption in case if normal mode was chosen. Naturally, if the energy saving mode was chosen, the total consumption would be lower as shown in Figure 5.2.



environment
1 agents

smartBuilding
SmartBuilding [1]

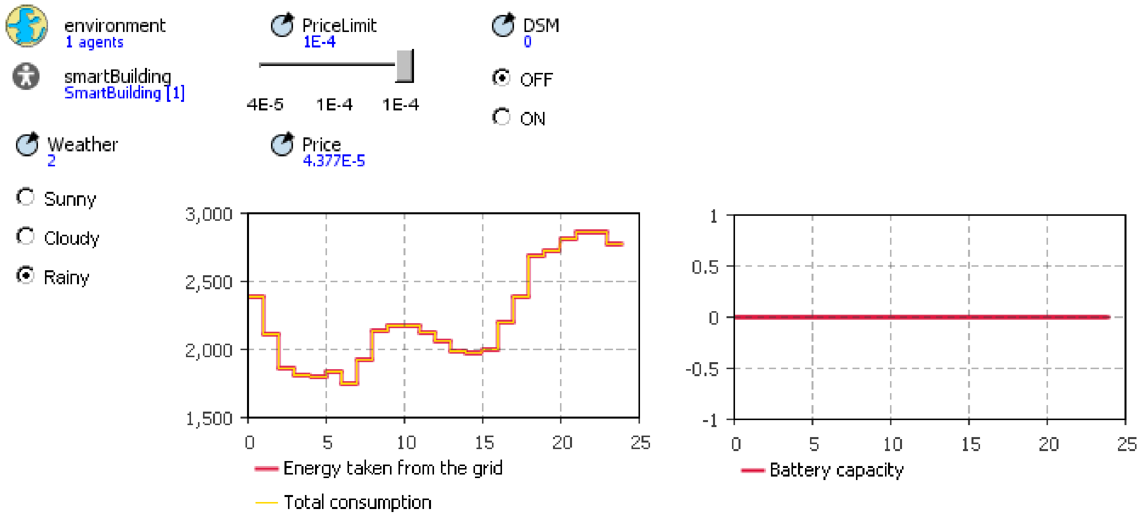
Weather
2
○ Sunny
○ Cloudy
● Rainy

PriceLimit
1E-4

Price
4.377E-5

DSM
0
● OFF
○ ON

Figure 5.1 Results of scenario 1 in case of normal water heater mode



environment
1 agents

smartBuilding
SmartBuilding [1]

PriceLimit
1E-4

DSM
0

● OFF
○ ON

Weather
2

○ Sunny
○ Cloudy
● Rainy

Price
4.377E-5

Figure 5.2 Results of scenario 1 in case of energy saving water heater mode

5.2. Scenario 2

The smart house is operating with full consumption and available energy from the solar cells (sunny day). There is no load decrease signal from the grid and the electricity price limit is set to 100 €/MWh. Two sub-scenarios conducted: the battery was empty and the battery was full prior to the occurrence of solar energy.

In this scenario, there is energy available from the solar cells which is then stored in the battery or used for powering the consumption. The use of available energy depends on the prior state of the battery.

Figure 5.3 shows the case when the battery was empty and the chosen water heater mode was normal. It is clearly visible from the graphs that all of the consumption is powered from the grid until the battery reaches its full capacity. Then the charging process stops and all of the energy from the solar cells is used to power the consumption which is shown by a deviation in two curves. At the time of high production from the solar cells, the consumption is lower so there is a surplus of energy produced from the solar cells; therefore it is sold back to the grid.

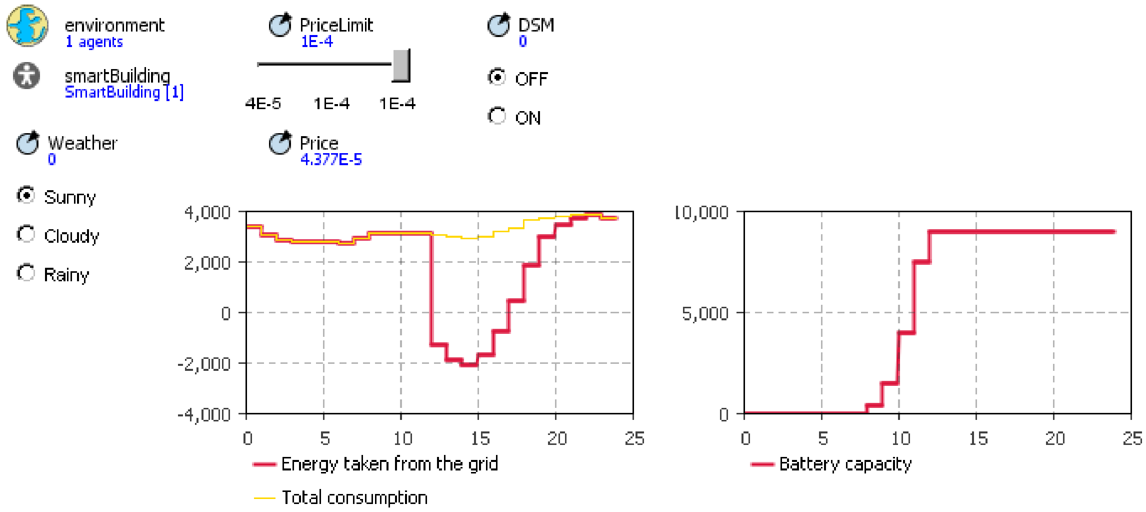

environment
1 agents
smartBuilding
SmartBuilding [1]
PriceLimit
1E-4
DSM
0
● OFF
○ ON
Weather
0
● Sunny
○ Cloudy
○ Rainy
Price
4.377E-5

Figure 5.3 Results of scenario 2 in case of normal water heater mode and previously empty battery

Figure 5.4 shows the case when the battery was fully charged prior to the occurrence of production from solar cells. This time, there is no charging of the battery so all of the produced energy is immediately used for powering the consumption. Again, there is a surplus of energy at certain point and it is sold back to the grid.

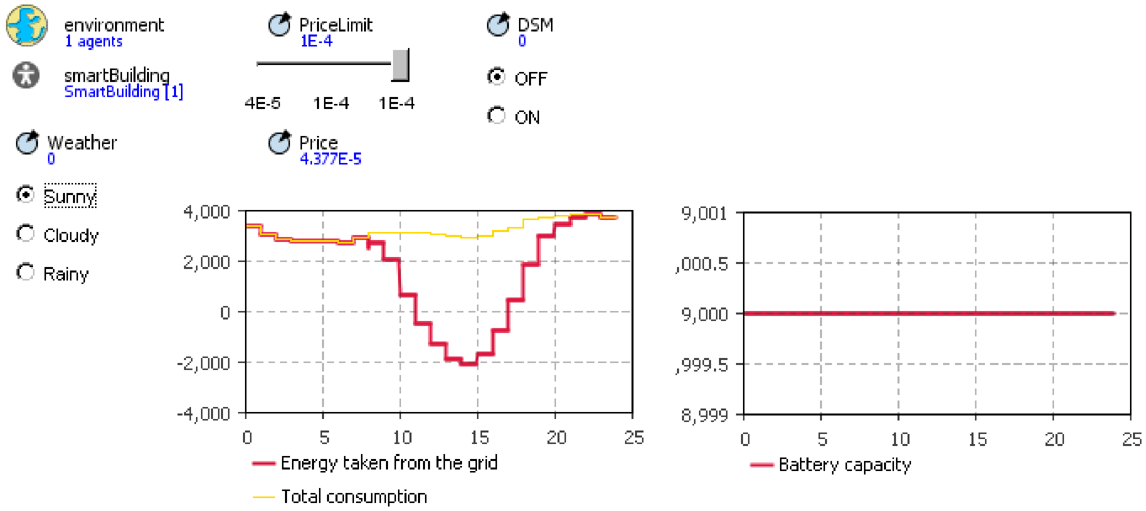

environment
1 agents
smartBuilding
SmartBuilding [1]
PriceLimit
1E-4
DSM
0
● OFF
○ ON
Weather
0
● Sunny
○ Cloudy
○ Rainy
Price
4.377E-5

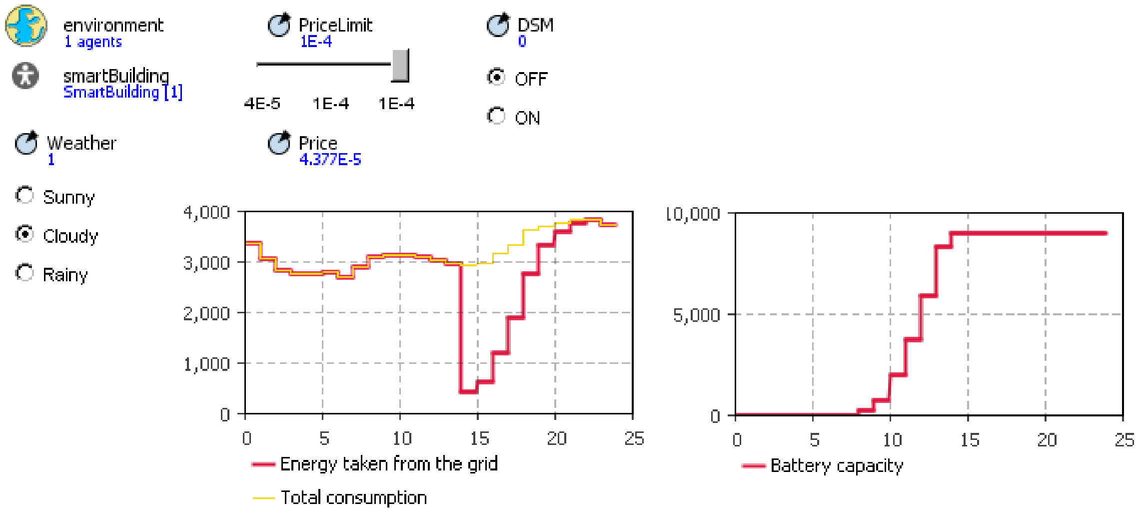
Figure 5.4 Results of scenario 2 in case of normal water heater mode and previously fully charged battery

The same results are obtained in the case when the chosen water heater mode was the energy saving mode. The only difference is that the total consumption was lower, hence the surplus of energy that was sold to the grid was bigger.

5.3. Scenario 3

The smart house is operating with full consumption and available energy from the solar cells (partly cloudy day). There is no load decrease signal from the grid and the electricity price limit is set to 100 €/MWh. Two sub-scenarios conducted: the battery was empty and the battery was full prior to the occurrence of solar energy.

Scenario 3 is very similar to the previous scenario. The only difference is that the production from the solar cells is lower because of the partly cloudy weather. Figure 5.5 shows the case when the battery was empty. As a consequence of a lower production, the time needed for the battery to fully charge is longer than in the previous scenario. Also, after the charging process is over, energy is used for powering the consumption, thus lowering the need for the energy from the grid. However, there is no surplus of energy that can be sold back to the grid. Figure 5.6 shows the behaviour of the smart house in case the battery was previously fully charged. As in the scenario 2, the smart house immediately uses the produced energy to power the consumption, but there is no surplus of energy.



environment
1 agents

smartBuilding
SmartBuilding [1]

PriceLimit
1E-4

DSM
0

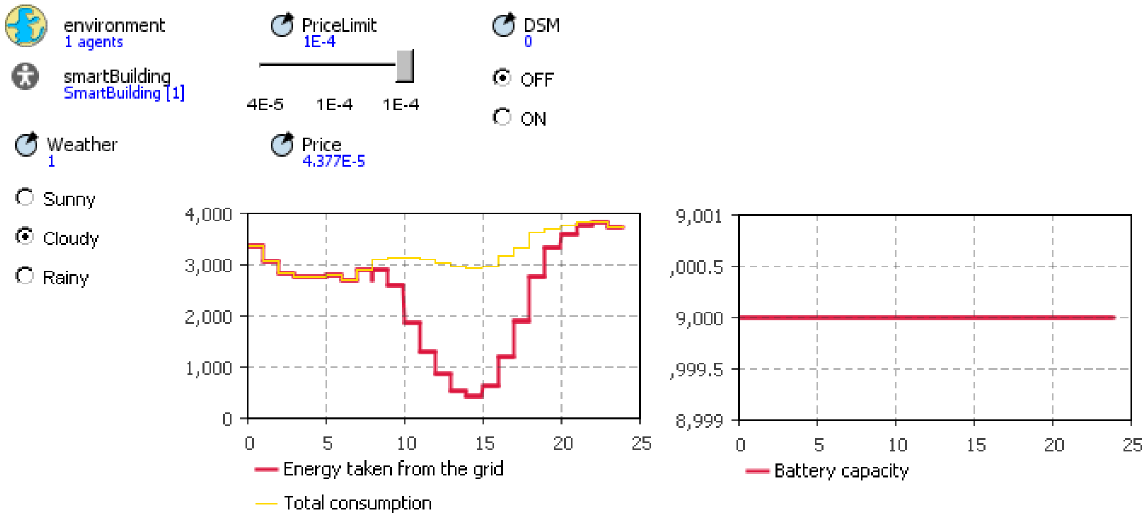
● OFF
○ ON

Weather
1

○ Sunny
● Cloudy
○ Rainy

Price
4.377E-5

Figure 5.5 Results of scenario 3 in case of normal water heater mode and previously empty battery



environment
1 agents

smartBuilding
SmartBuilding [1]

Weather
1

○ Sunny
● Cloudy
○ Rainy

PriceLimit
1E-4

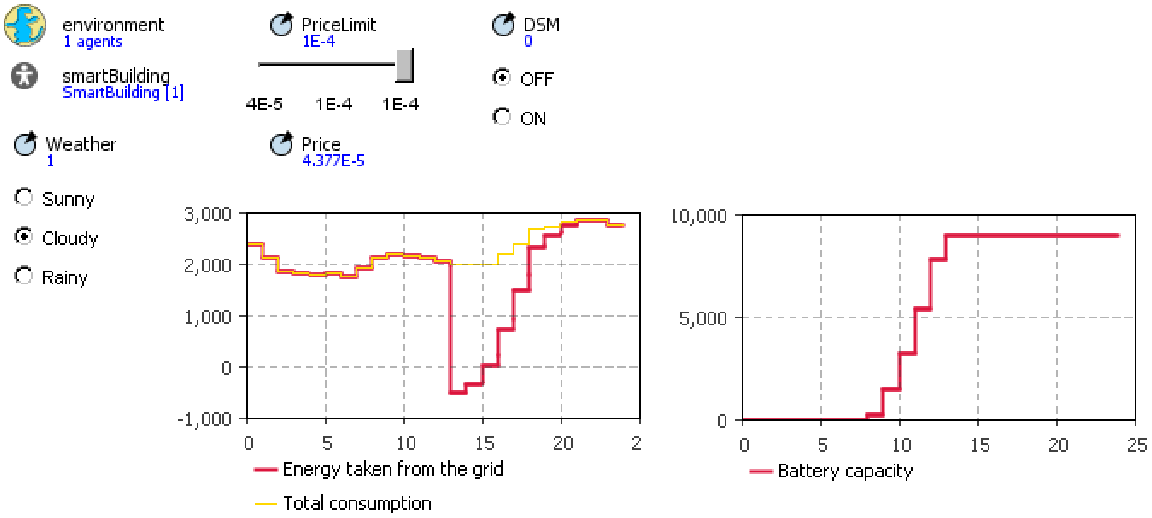
Price
4.377E-5

DSM
0

● OFF
○ ON

Figure 5.6 Results of scenario 3 in case of normal water heater mode and previously fully charged battery

Both of these sub-scenarios were conducted in case the chosen water heater mode was normal operation. On the other hand, if the chosen mode was the energy saving mode, consequently the total consumption would be lower and in certain periods there would be a surplus of energy even though the production from the solar cells in only 50% of their nominal power (Figure 5.7).



environment
1 agents

smartBuilding
SmartBuilding [1]

Weather
1

○ Sunny
● Cloudy
○ Rainy

PriceLimit
1E-4

Price
4.377E-5

DSM
0

● OFF
○ ON

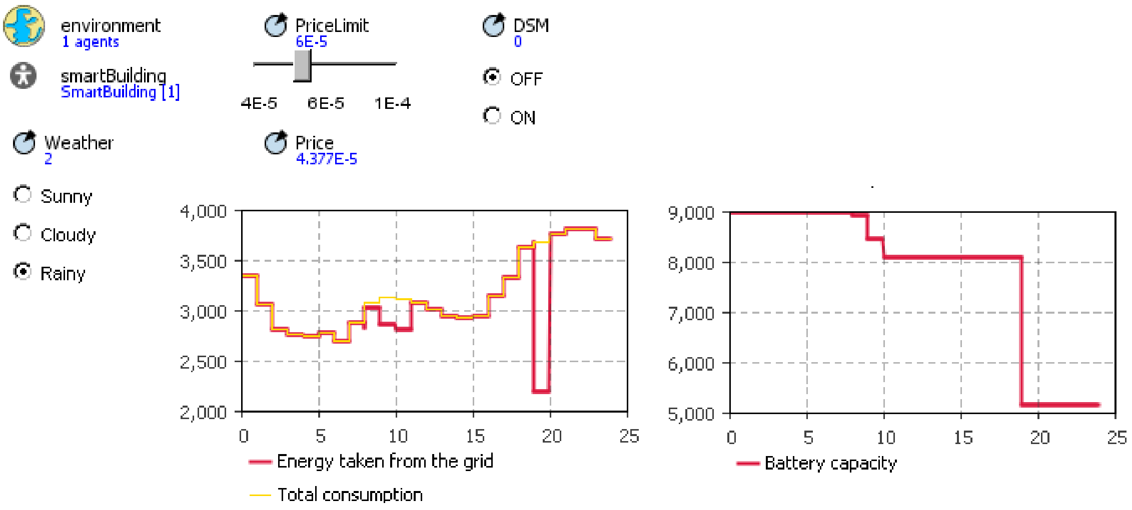
Figure 5.7 Results of scenario 3 in case of energy saving water heater mode and previously empty battery

5.4. Scenario 4

The smart house is operating with full consumption without the availability of solar energy (rainy day). There is no load decrease signal from the grid and the electricity price limit is set to 60 €/MWh. Two sub-scenarios conducted: the battery was empty and the battery was full prior to the occurrence of solar energy.

These two sub-scenarios show how the smart house behaves if the set electricity price limit set by the user is lower than the current market price. In case the battery was previously empty, there is no difference between this scenario and scenario 1. The reason is that the house has no alternative resources such as production from the solar cells or energy stored in the battery; therefore it has to accept the market price and buy all the energy from the grid.

However, if the battery was previously charged, in the times when the market price exceeds the price limit, part of the consumption will be supplied by discharging the battery to lower the amount of energy taken from the grid which can be seen as two drops in the red curve as well as from the curve that represent battery capacity (Figure 5.8). The drop in the evening hours is bigger due to higher market price than in the morning which means the user will get less energy from the grid for the money he is willing to pay.



environment
1 agents

smartBuilding
SmartBuilding [1]

PriceLimit
6E-5

DSM
0

● OFF
○ ON

Weather
2

○ Sunny
○ Cloudy
● Rainy

Price
4.377E-5

Figure 5.8 Results of scenario 4 in case of normal water heater mode and previously fully charged battery

5.5. Scenario 5

The smart house is operating with full consumption and available energy from the solar cells (sunny day). There is no load decrease signal from the grid and the electricity price limit is set to 60 €/MWh. Two sub-scenarios conducted: the battery was empty and the battery was full prior to the occurrence of solar energy.

The sub-scenario with the previously empty battery is shown in Figure 5.9. The curve can be divided into three parts: the first part is the period of morning peak hours, second one is the period though the day and the third one is the period of evening peak hours.

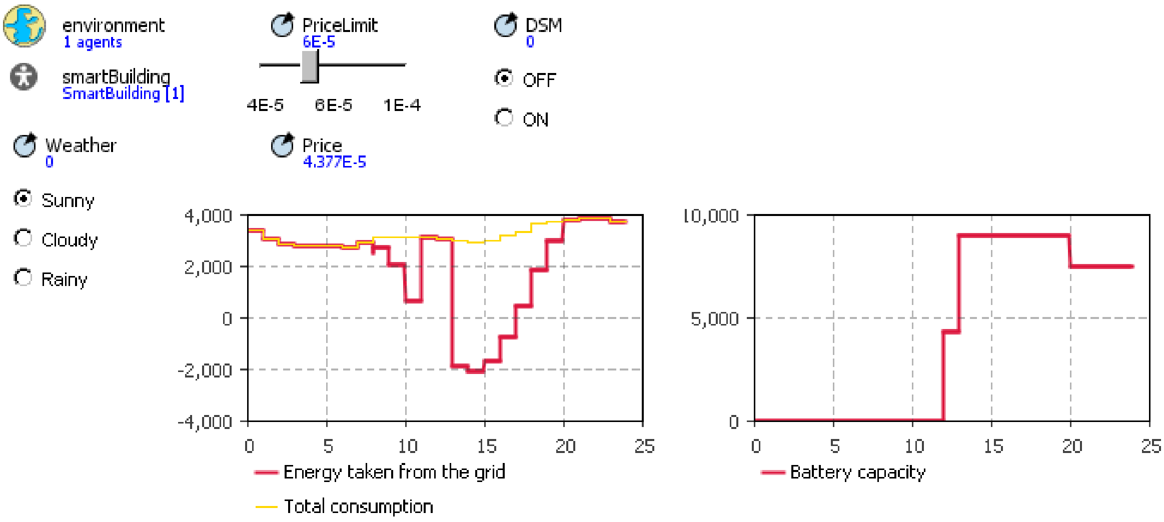
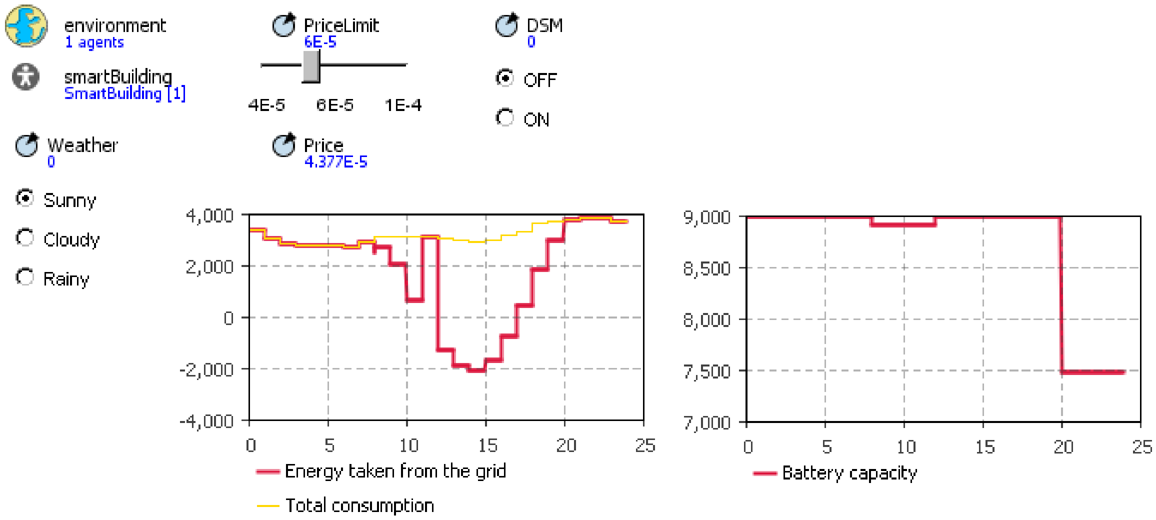

environment
1 agents
smartBuilding
SmartBuilding [1]
PriceLimit
6E-5
DSM
0
● OFF
○ ON
Weather
0
● Sunny
○ Cloudy
○ Rainy
Price
4.377E-5

Figure 5.9 Results of scenario 5 in case of normal water heater mode and previously empty battery

In the period of morning peak hours, the price is higher than the set price limit which leads to solar cells being directly used for powering the consumption and not for charging the battery. Afterwards, the price gets below the limit and the energy from the solar cells is used to charge the battery. When the charging process is over, the energy is again used for supplying the consumption. In the evening peak hours there is still some energy from the solar cells in certain periods but it is not enough to keep the total amount of energy taken from the grid below the limit set by the user. Hence, the battery is discharged to supply part of the consumption. When the market price gets below the limit again, total consumption is supplied from the grid.

Other simulated sub-scenario is the one where the battery was previously charged (Figure 5.10). Comparing it to the first simulation, there is one crucial difference: in the morning peak hours when the market price exceeds the price limit, there is a battery discharge period to lower the energy taken from the grid. Afterwards, charging to the full capacity and usage of produced energy for meeting the consumption follow. The behaviour of the smart house in the period of evening peak hours is the same as in the previous sub-scenario.



environment
1 agents

smartBuilding
SmartBuilding [1]

Weather
0

● Sunny
○ Cloudy
○ Rainy

PriceLimit
6E-5

Price
4.377E-5

DSM
0

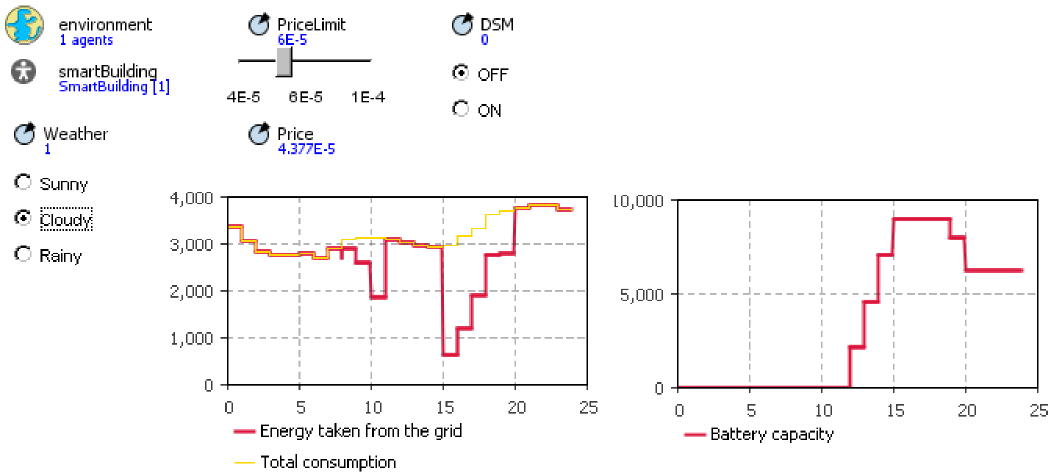
● OFF
○ ON

Figure 5.10 Results of scenario 5 in case of normal water heater mode and previously fully charged battery

5.6. Scenario 6

The smart house is operating with full consumption and available energy from the solar cells (partly cloudy day). There is no load decrease signal from the grid and the electricity price limit is set to 60 €/MWh. Two sub-scenarios conducted: the battery was empty and the battery was full prior to the occurrence of solar energy.

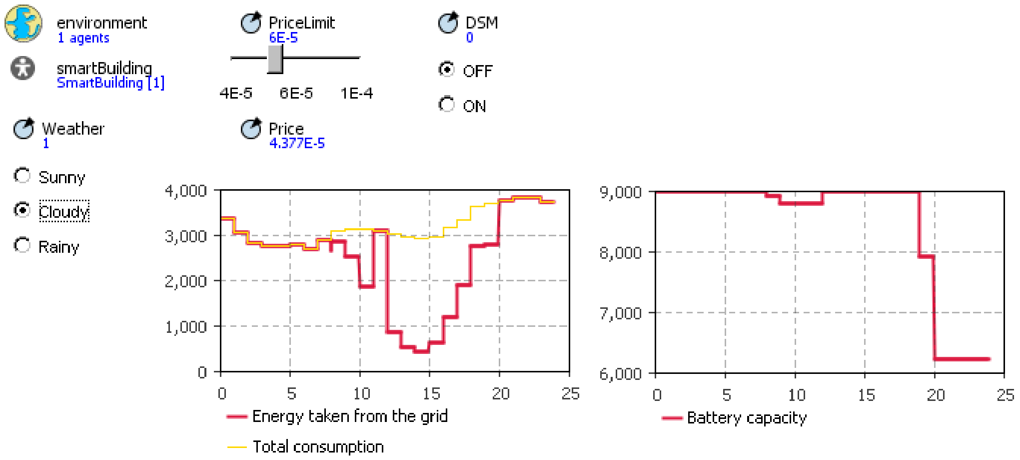
The behaviour of the smart house in scenario 6 is very similar to the one in scenario 5. When the battery was empty (Figure 5.11), even though the energy from the solar cells was used for direct supply of the loads, there was no possibility to lower the total energy taken from the grid below the limit in the morning peak hours by discharging the battery. Afterwards, there is charging of the battery and then direct supplying from the solar cells for part of the consumption. However, there is difference in behaviour in the evening peak hours. There is a bigger discharge of the battery to lower the total energy taken from the grid. This is due to the fact there is less produced energy than on a sunny day, thus there is not enough energy to maintain the total energy from the grid below the set limit without discharging the battery.



environment
1 agents
smartBuilding
SmartBuilding [1]
PriceLimit
6E-5
DSM
0
● OFF
○ ON
Weather
1
Price
4.377E-5
○ Sunny
● Cloudy
○ Rainy

Figure 5.11 Results of scenario 6 in case of normal water heater mode and previously empty battery

In the sub-scenario where the battery was previously charged, the behaviour of the smart house is completely the same with an exception of discharging the battery also in the morning peak hours (Figure 5.12).



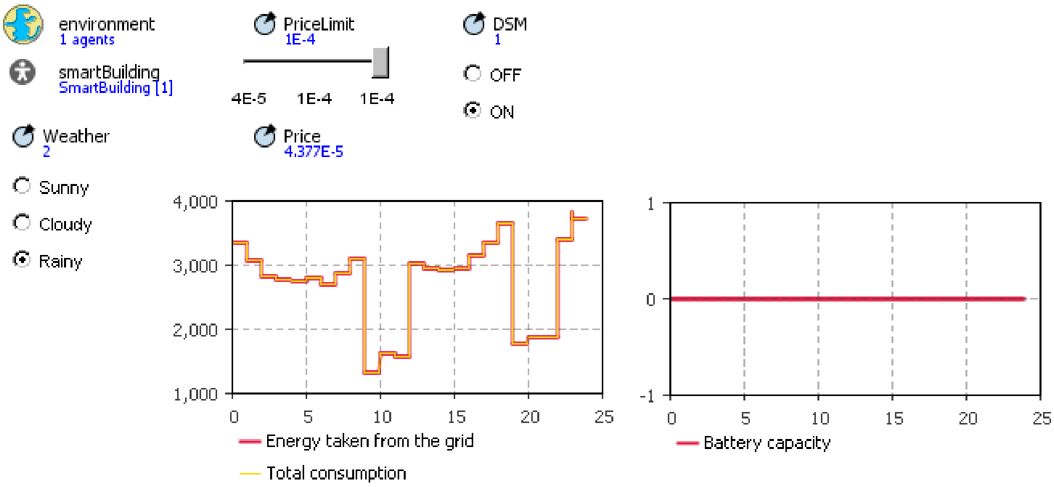
environment
1 agents
smartBuilding
SmartBuilding [1]
PriceLimit
6E-5
DSM
0
● OFF
○ ON
Weather
1
Price
4.377E-5
○ Sunny
● Cloudy
○ Rainy

Figure 5.12 Results of scenario 6 in case of normal water heater mode and previously fully charged battery

5.7. Scenario 7

The smart house is operating with full consumption without the availability of solar energy (rainy day). There is a load decrease signal from the grid in two peak hour periods and the electricity price limit is set to 100 €/MWh.

There are two periods with load decrease signal – one in the morning and one in the evening. Signal in the morning requires a decrease in consumption of 1000 Wh/h while the one in the evening requires a decrease of 2000 Wh/h. Smart loads are directly controlled and turned off which can be seen from two drops in the consumption curve in the case the water heater mode is set to normal (Figure 5.13). Obviously, the total consumption is lowered as well as the total energy taken from the grid.



environment
1 agents

smartBuilding
SmartBuilding [1]

PriceLimit
1E-4

DSM
1

○ OFF
● ON

Weather
2

○ Sunny
○ Cloudy
● Rainy

Price
4.377E-5

Figure 5.13 Results of scenario 7 in case of normal water heater mode and load decrease signal from the grid

When the load decrease signal first appears, the controller turns off the appliances in order of the priority lists which means all of the appliance (except the lights that are not switched on) will be turned off to reach 1000 Wh/h (Figure 5.14). After all of the appliances are turned off, the controller realises it can turn back on all of the appliances except for the water heater which exceeds 1000 Wh/h on its own (Figure 5.15). After the signal from the grid is gone, all the appliances are turned back on.

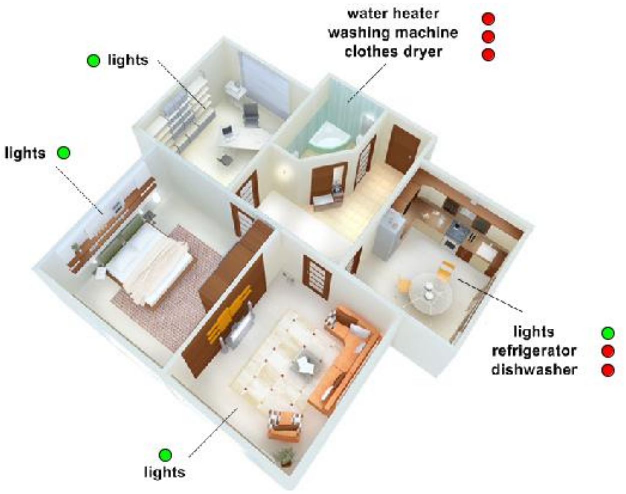


Figure 5.14 State of smart appliances when the load decrease signal appears

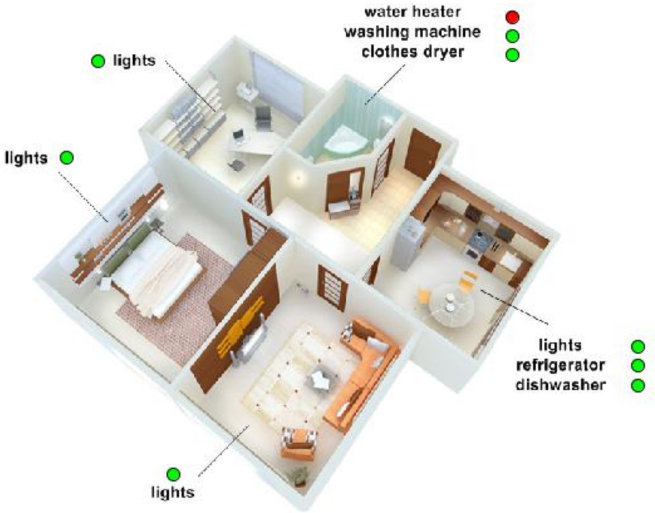


Figure 5.15 State of smart appliances in morning peak hours

When load decrease signal in the evening appears, the controller turns off all the smart appliances including the lights (except for bedroom lights that are not yet turned on) to reach the amount of 2000 Wh/h. However, it is still not enough, so when the bedroom lights turn on, they are immediately dimmed to 50% (Figure 5.16). After 3 hours, the water heater is automatically turned on while the rest of the smart loads are still turned off (Figure 5.17). When the signal from the grid vanishes, the appliances are turned back on.

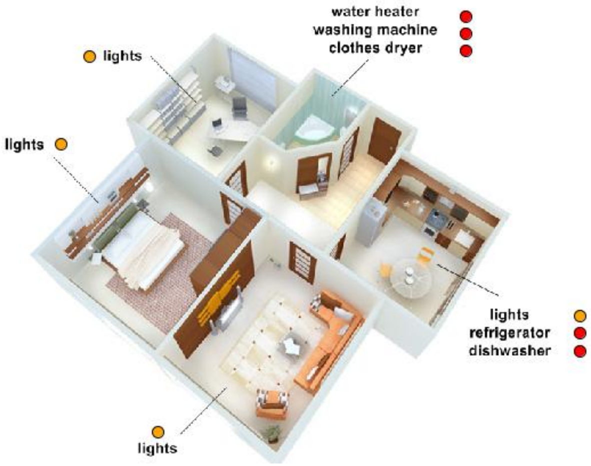


Figure 5.16 State of smart appliances in evening peak hours

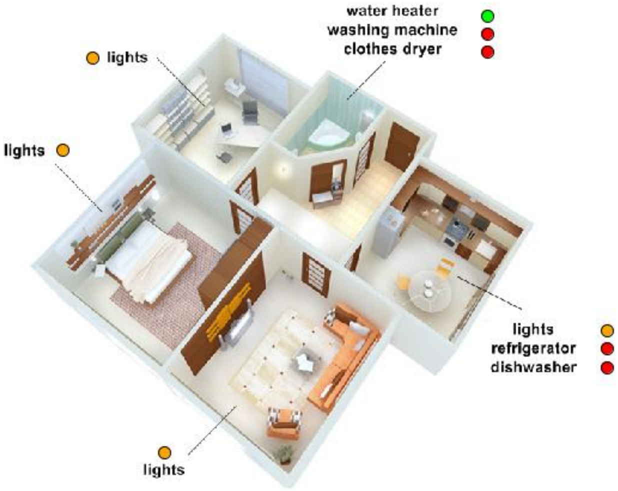


Figure 5.17 State of smart appliances after 3 hours when the water heater is automatically turned on

The results are very similar in the case on energy saving water heater mode. The only difference is that there is no turning back on of appliances in the morning because the heater itself does not reach the required decrease of 1000 Wh/h.

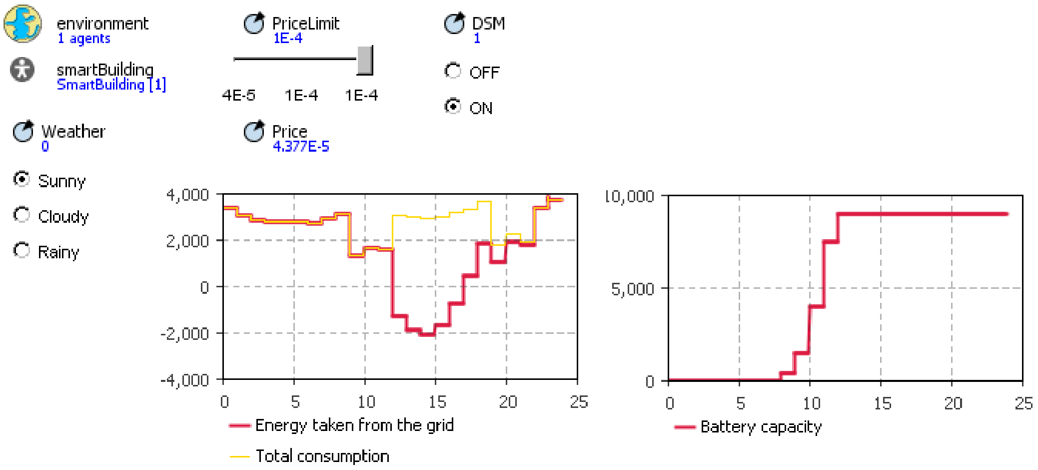
5.8. Scenario 8

The smart house is operating with full consumption and available energy from the solar cells (sunny day). There is a load decrease signal from the grid in two peak hour periods and the electricity price limit is set to 100 €/MWh. Two sub-scenarios conducted: the battery was empty and the battery was full prior to the occurrence of solar energy.

This scenario is a combination of already explained scenarios number 2 and 7. The energy from the solar cells is first used to charge the battery and then to directly supply the loads.

There are two drops in consumption due to load decrease signal from the grid. In the morning hours, the consumption curve follows the curve of energy taken from the grid because the solar energy is used to charge the batteries. However, in the evening peak hours the two curves do not overlap due to some production from the solar cells which is used to supply part of the loads (Figure 5.18).

The results in case the battery was previously fully charged are the same except in the morning hours when part of the energy from solar cells is used to power part of the consumption.



environment
1 agents

smartBuilding
SmartBuilding [1]

PriceLimit
1E-4

DSM
1

○ OFF
● ON

Weather
0

● Sunny
○ Cloudy
○ Rainy

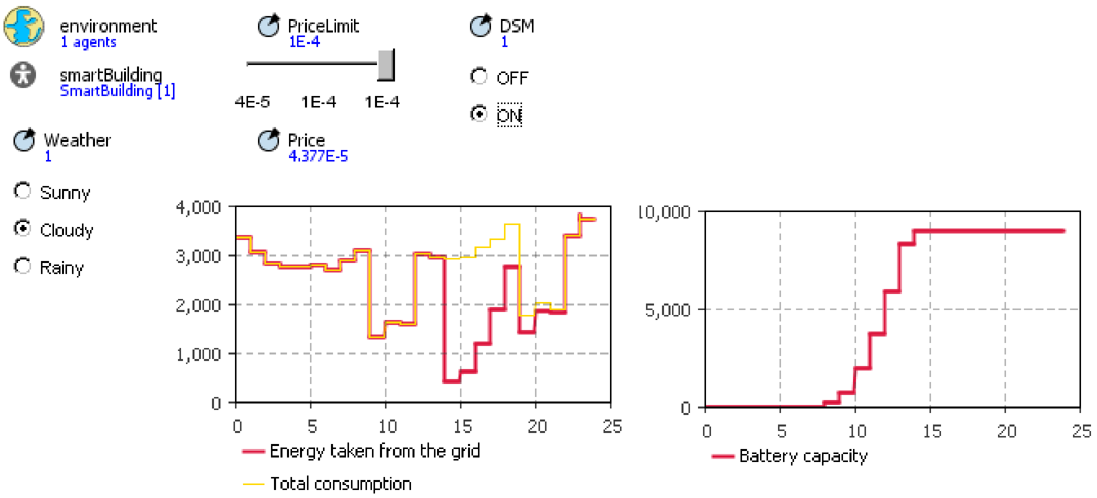
Price
4.377E-5

Figure 5.18 Results of scenario 8 in case of normal water heater mode and previously empty battery

5.9. Scenario 9

The smart house is operating with full consumption and available energy from the solar cells (partly cloudy day). There is a load decrease signal from the grid in two peak hour periods and the electricity price limit is set to 100 €/MWh. Two sub-scenarios conducted: the battery was empty and the battery was full prior to the occurrence of solar energy.

Scenario 9 simulates the same results as scenario 8 in both sub-scenarios with the exception of the production from the solar cells which is lower (Figure 5.19, Figure 5.20).



environment 1 agents

smartBuilding SmartBuilding [1]

PriceLimit 1E-4

DSM 1

○ OFF

● ON

Weather 1

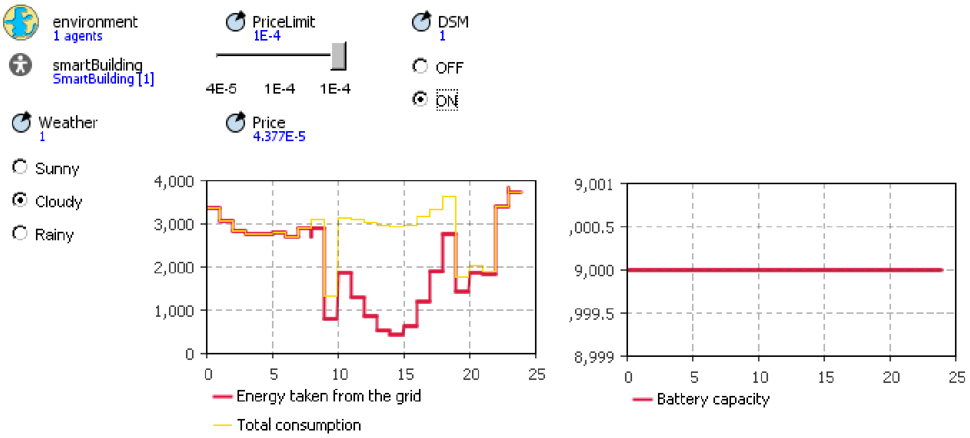
○ Sunny

● Cloudy

○ Rainy

Price 4.377E-5

Figure 5.19 Results of scenario 9 in case of normal water heater mode and previously empty battery



environment 1 agents

smartBuilding SmartBuilding [1]

PriceLimit 1E-4

DSM 1

○ OFF

● ON

Weather 1

○ Sunny

● Cloudy

○ Rainy

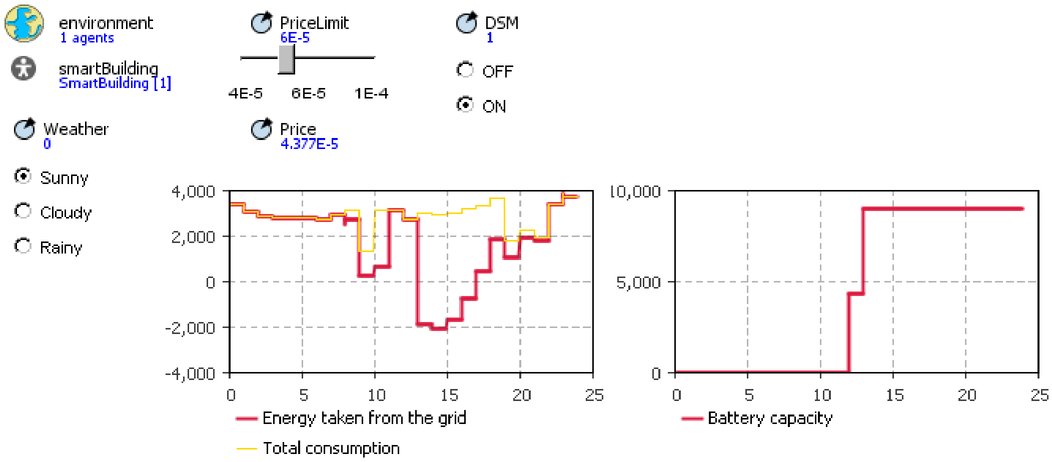
Price 4.377E-5

Figure 5.20 Results of scenario 9 in case of normal water heater mode and previously fully charged battery

5.10. Scenario 10

The smart house is operating with full consumption and available energy from the solar cells (sunny day). There is a load decrease signal from the grid in two peak hour periods and the electricity price limit is set to 60 €/MWh.

This scenario is similar to scenario number 8. The main difference is that now there is an electricity price limit set to 60 €/MWh. This limit does not influence the direct load control, however it influences the behaviour of smart house in such way that the battery is charged after the morning peak hours are over. Until then, the energy from the solar cells is used for supplying the loads and afterwards for charging the battery (Figure 5.21). If the battery was previously fully charged, there would be a period of discharge in the morning hours.



environment 1 agents

smartBuilding SmartBuilding [1]

PriceLimit 6E-5

DSM 1

○ OFF

● ON

Weather 0

● Sunny

○ Cloudy

○ Rainy

Price 4.377E-5

Figure 5.21 Results of scenario 10 in case of normal water heater mode and previously empty battery

5.11. Short overview of the results

A short overview of total consumption of the smart house and total energy taken from the grid in different scenarios is given in Table 8.

It is obvious that a photovoltaic system and battery storage influence the total energy taken from the grid while the direct load control influences the total consumption of the house.

Table 8 Short overview of the results for various scenarios[4]

Scenario	**Weather**	**Load decrease signal from the grid**	**Electricity price limit [€/MWh]**	**Previous battery state**	**Daily consumption [kWh]**	**Energy taken from the grid [kWh]**
1	rainy	no	100	empty	80,654	80,654
2	sunny	no	100	empty	80,654	58,352
2	sunny	no	100	charged	80,654	52,642
3	cloudy	no	100	empty	80,654	69,584
3	cloudy	no	100	charged	80,654	62,444
4	rainy	no	60	empty	80,654	80,654
4	rainy	no	60	charged	80,654	78,486

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[4] All of the results are given for scenarios where the water heater mode was set to normal (1500 W)

5	sunny	no	60	empty	80,654	58,315
5	sunny	no	60	charged	80,654	52,148
6	cloudy	no	60	empty	80,654	70,788
6	cloudy	no	60	charged	80,654	61,415
7	rainy	yes	100	empty	69,374	69,374
8	sunny	yes	100	empty	69,374	45,633
8	sunny	yes	100	charged	69,374	42,608
9	cloudy	yes	100	empty	69,374	55,304
9	cloudy	yes	100	charged	69,374	51,164
10	sunny	yes	60	empty	69,374	48,687

6. Cost and benefit analysis of a smart house

Costs for implementing a smart house have been classified into several categories: costs for smart appliances, costs for dimmable lightning system, costs for photovoltaic system and other costs.

Currently, there is no high bid of smart appliances due to big costs of production and therefore bigger price that most of the consumers are still not willing to pay. However, Whirpool has recently released its new line of smart appliances [58] whose prices have been used for this analysis. Also, costs for the water heater are based on GE GeoSpring smart water heater [59]. The costs for dimmable lightning system include prices for the light bulbs [60] as well as for the switches and dimmers [61].

When installing renewable resources such as photovoltaics, except for costs from equipment, there are also various costs such as a fee for connection to the grid, studies and elaborations of impact to the grid and similar. In this case, implemented photovoltaic system has nominal power of 5 kW, so 20 solar panels REC 250PE with nominal power 250 W have been chosen [62]. The inverter installed between the solar panels and the grid must have minimal power of 5000 W. Therefore, the chosen inverter is SMA SunnyBoy 5000US [63].

Other costs imply the costs for smart meter [64], energy management system [65], communication upgrades and home automation system with sensors and actuators [65], wired infrastructure [66] and energy storage costs, in this case costs for a 9 kWh Li-Ion battery [40].

Total costs for a basic implementation of smart house are given in the table (Table 9).

Table 9 Costs for implementing a smart house

ITEM	PRICE PER ITEM [€]	QUANTITY [€]	TOTAL COST [€]
SMART APPLIANCES			
Water heater	999,31	1	999,31
Washing machine	1230,09	1	1230,09
Clothes dryer	1230,09	1	1230,09
Refrigerator	1460,88	1	1460,88
Water heater	730,06	1	730,06

DIMMABLE LIGHTNING SYSTEM			
Dimmers	25,00	14	350,00
Switches	11,25	14	157,50
Bulbs	8,37	14	117,18
PHOTOVOLTAIC SYSTEM			
Solar panels	190,00	20	3800,00
Inverter	1961,69	1	1961,69
Connection to the grid		1	1600,00
Other specific costs		1	2100,00
OTHER			
Smart meter	170,21	1	170,21
EMS portal	153,86	1	153,86
Communication upgrades and home automation	3846,45	1	3846,45
Wired infrastructure	1923,23	1	1923,23
Battery storage	769,29[5]	9	6923,61
TOTAL COSTS			**28754,15**

Smart house gains revenues from selling the energy from the solar cells to the grid as well as from savings due to direct load control during peak hours. According to a case study in Norway [67], typical household saves 1 kWh/h during peak hours by turning off the smart appliances.

As far as the sale of energy from solar cells to the grid, the calculation of total revenues is complicated. It is known that the sun is intermittent resource thus it is hard to precisely calculate how much energy can be produced in the small solar power plant. In this analysis, RETScreen program is used to calculate annual produced energy. After entering different input data such as location, nominal power and efficiency of solar cells, the program calculated annual production of 5,274 MWh. Detailed overview of production by months is given in the table (Table 10).

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[5] The price is given in €/kWh

Table 10 Estimated monthly production from 5 kW solar cells for Trondheim, Norway

Month	Produced electricity [MWh]
January	0,196
February	0,209
March	0,461
April	0,546
May	0,742
June	0,660
July	0,736
August	0,602
September	0,434
October	0,360
November	0,187
December	0,140

From the given data, it was necessary to estimate everyday production hour by hour for an average day. After deducting the energy used for charging the battery and by using a solar calculator from the US National Renewable Energy Laboratory [68], the following tables were obtained (Table 11, Table 12).

Table 11 Estimated hourly production from 5 kW solar cells (January to June) for Trondheim

Hour	January [kWh/h]	February [kWh/h]	March [kWh/h]	April [kWh/h]	May [kWh/h]	June [kWh/h]
0	0	0	0	0	0	0
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0,367	0,738	0,081
8	0	0	0	1,062	1,420	0,697
9	0	0	0,458	1,530	1,884	1,200
10	0	0	1,488	1,711	1,984	1,701
11	0,899	0,548	1,850	2,182	2,344	2,416
12	0,698	1,912	2,277	2,308	2,972	2,747
13	0,768	1,682	2,214	2,297	3,307	2,815

14	1,427	1,593	2,058	2,133	3,212	2,865
15	1,269	0,435	1,724	1,732	2,271	2,583
16	0	0	0,926	1,261	1,512	1,820
17	0	0	0,063	0,488	1,231	1,035
18	0	0	0	0	0,345	0,766
19	0	0	0	0	0	0,160
20	0	0	0	0	0	0,009
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0

Table 12 Estimated hourly production from 5 kW solar cells (July to December) for Trondheim

Hour	July [kWh/h]	August [kWh/h]	September [kWh/h]	October [kWh/h]	November [kWh/h]	December [kWh/h]
0	0	0	0	0	0	0
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0,002	0	0	0	0	0
6	0,070	0,002	0	0	0	0
7	0,577	0,107	0,051	0	0	0
8	0,936	0,686	1,005	0	0	0
9	1,357	1,147	1,438	0,973	0	0
10	1,796	1,656	0,324	2,195	0	0
11	2,612	2,101	0,894	2,527	0,482	0,577
12	3,597	2,485	1,447	2,251	1,304	1,296
13	4,078	2800	1,803	1,080	1,913	1,141
14	3,116	2049	2,050	0,862	1,221	0,005
15	1,748	1949	1,829	0,634	0	0
16	0,576	1242	1,383	0,003	0	0
17	1,013	1157	0,763	0	0	0
18	0,782	0,619	0,033	0	0	0
19	0,208	0,019	0	0	0	0
20	0,022	0	0	0	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0

23	0	0	0	0	0	0

Of course, daily energy production is not the same every day in a month. However, to simplify this calculation, it was assumed that given average hourly production was throughout the whole month. After obtaining total produced energy, it was necessary to define battery charging. In this analysis, the house fully charges the battery once a week and sells that energy in the peak hour with maximal price. It is important if the battery is discharged during the winter period or the rest of the year. As the consumption curve is different for winter months (January, February and December) and the rest of the year, two electricity price curves were obtained – one from 15.01.2013. and the other from 21.03.2013. which was previously used in the model.

Short overview of smart building's yearly revenues is given in the table (Table 13).

Table 13 Yearly revenues of a smart building in Norway

	Total energy [kWh/year]	Price [€/MWh]	Total [€/year]
Stored energy – winter period	108	39,27	4,24
Stored energy – rest of the year	360	95,69	34,45
Directly sold energy from the solar cells	4807	depends on the hour	270,35
Savings from load control – winter period	90	depends on the hour	25,65
Savings from load control – rest of the year	275	depends on the hour	155,18

Except for costs and revenues, an important part of the analysis are the financial parameters which are given in Table 14.

Table 14 Financial parameters used in the analysis

Parameter	%
Share of own funds	50
Loan share	50
Interest rate[6]	6,31
Inflation rate[7]	2,6

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[6] [69]

[7] [70]

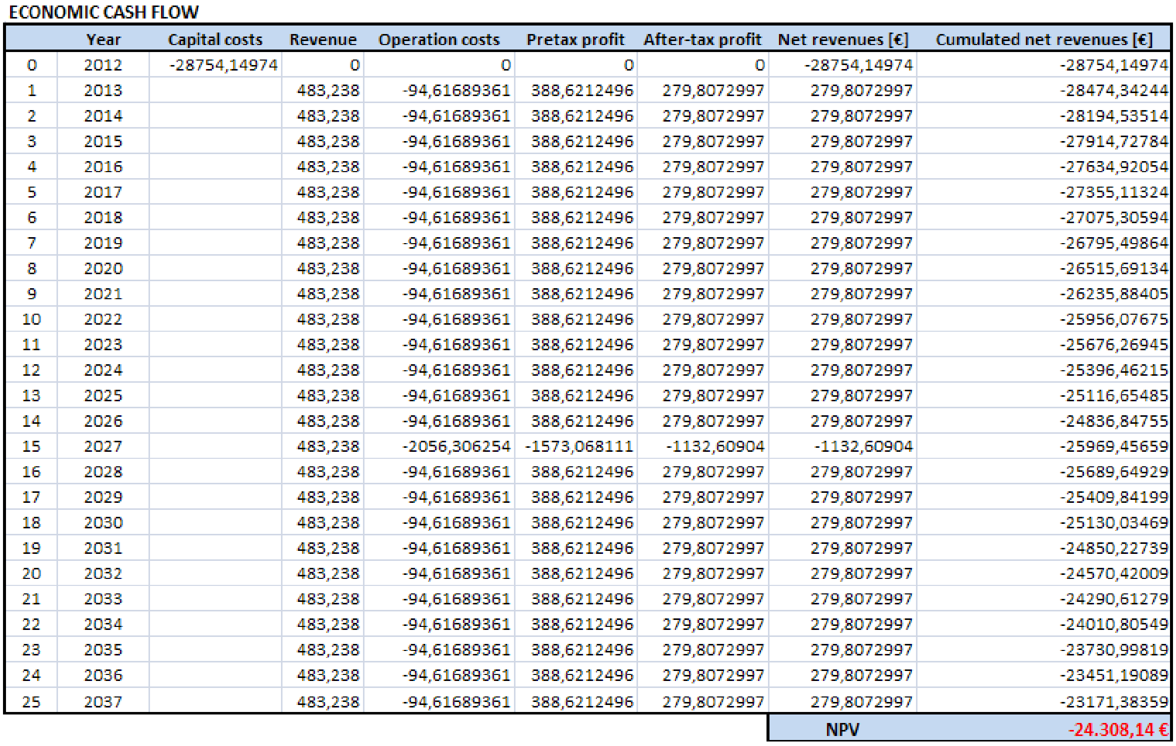
Income tax[8]	28

With the assumption that the loan duration is 15 years, the annuity can easily be calculated from the formula:

$$annuity = \frac{loan\ share}{100} * capital\ costs * \left(\frac{k}{100} + \frac{i}{100}\right) * \frac{(1 + \frac{k}{100} + \frac{i}{100})^t}{(1 + \frac{k}{100} + \frac{i}{100})^t - 1}$$

where *k* is the interest rate, *i* is the inflation rate and *t* is loan duration.

To estimate the profitability of installing the smart house, economic cash flow was conducted. From the economic cash flow, net present value was calculated and it was obtained that it is negative (Figure 2.1). This means that it is not profitable to implement a smart house in today's environment in Norway.



ECONOMIC CASH FLOW

	Year	Capital costs	Revenue	Operation costs	Pretax profit	After-tax profit	Net revenues [€]	Cumulated net revenues [€]
0	2012	-28754,14974	0	0	0	0	-28754,14974	-28754,14974
1	2013		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-28474,34244
2	2014		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-28194,53514
3	2015		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-27914,72784
4	2016		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-27634,92054
5	2017		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-27355,11324
6	2018		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-27075,30594
7	2019		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-26795,49864
8	2020		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-26515,69134
9	2021		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-26235,88405
10	2022		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-25956,07675
11	2023		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-25676,26945
12	2024		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-25396,46215
13	2025		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-25116,65485
14	2026		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-24836,84755
15	2027		483,238	-2056,306254	-1573,068111	-1132,60904	-1132,60904	-25969,45659
16	2028		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-25689,64929
17	2029		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-25409,84199
18	2030		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-25130,03469
19	2031		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-24850,22739
20	2032		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-24570,42009
21	2033		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-24290,61279
22	2034		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-24010,80549
23	2035		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-23730,99819
24	2036		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-23451,19089
25	2037		483,238	-94,61689361	388,6212496	279,8072997	279,8072997	-23171,38359
							NPV	-24.308,14 €

Figure 6.1 Results of the economic cash flow for a smart house in Norway

This result was expected due to big capital costs and it can be concluded that this is the principal reason for customers' reluctance in regards to smart houses. Therefore, it is

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[8] [71]

necessary to provide feed-in tariffs for electricity from solar cells as well as some incentives for introduction of smart appliances. However, it is expected that the technology will rapidly evolve which will lead to price decrease for smart appliances, battery storage and solar cells, so the costs in the future will be considerably less.

In addition, it has to be kept in mind that gaining profit from the smart house is not the main reason for its implementation. There are many other benefits to which it is difficult to add economic value such as helping the grid operation, long-term helping in reducing market prices and lowering the total consumption of households.

6.1. Cost and benefit analysis for Croatia

The same analysis has been conducted for the case where the smart house is located in Zagreb, Croatia. However, due to the change of the location, some of the parameters also had to be changed. The first changed parameter is production from the solar cells which has been estimated for the new location with RETScreen program. The obtained results for annual production of energy are given in the table (Table 15).

Table 15 Estimated monthly production from 5 kW solar cells for Zagreb, Croatia

Month	Produced electricity [MWh]
January	0,253
February	0,357
March	0,506
April	0,615
May	0,706
June	0,683
July	0,748
August	0,698
September	0,615
October	0,484
November	0,262
December	0,203
ANNUAL	**6,130**

The second important change in the analysis is the prices for the electricity. Unlike Norway, Croatia has no developed electricity market. In addition, households are charged for consumption according to Time-of-Use tariffs and there is an incentive price for energy produced in renewable resources. If the photovoltaic system has been installed prior to 1st June 2012, the price and incentive period differ than in the case the system has been installed afterwards when the incentive prices were lowered and incentive period was extended from 12 to 14 years. Mentioned tariffs and prices are listed in the table (Table 16 [75-77]).

Table 16 Time-of-Use tariffs and incentive prices in Croatia

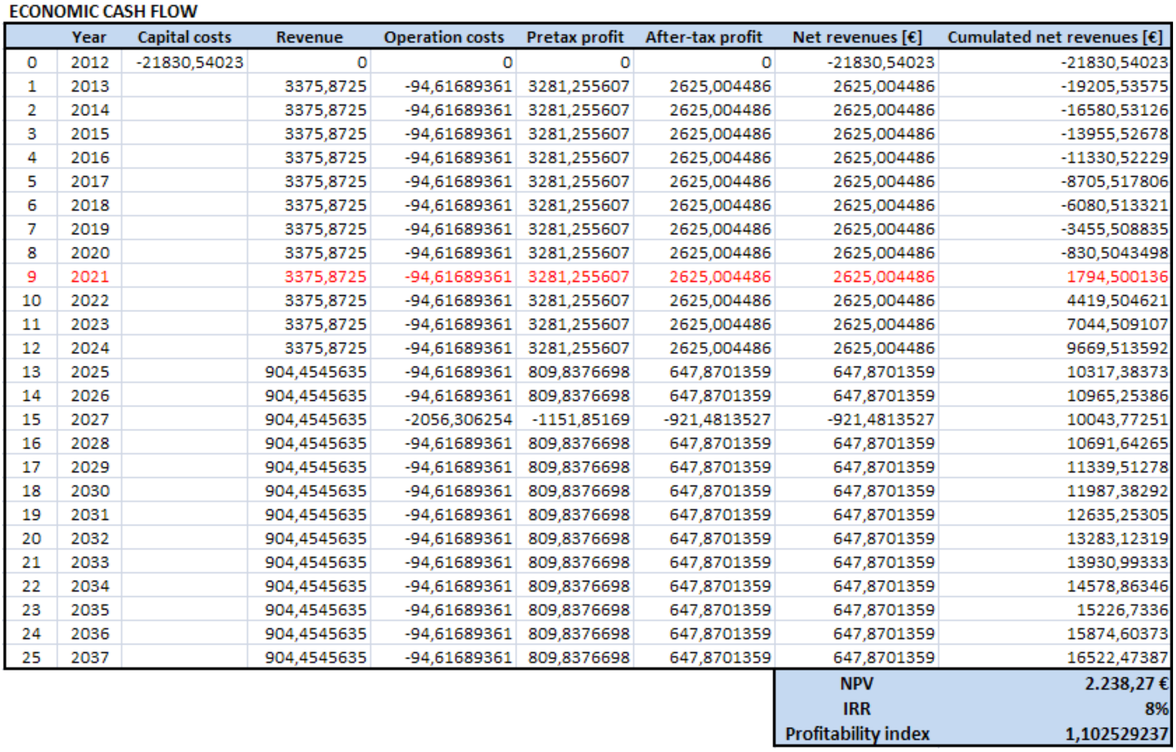
	Electricity price [€/kWh]
High tariff period for households	0,1505
Low tariff period for households	0,0739
Flat tariff model for households	0,1386
Incentive price for renewable energy prior 1.6.2012.	0,5418
Incentive price for renewable energy after 1.6.2012.	0,3471

Considering the change of electricity price, the revenues also change. Energy from the solar cells is directly sold to the grid (there is no need for the battery so the capital costs are somewhat lower) and savings from the demand side management are calculated at a high tariff price. It is assumed that the average production price for electricity is equal to the price of flat tariff model. Table (Table 17) shows the revenues for two cases of incentive prices.

Table 17 Revenues of a smart house in cases with different incentive prices in Croatia

	Total energy [kWh/year]	**Price [€/kWh]**	**Total [€/year]**
PV SYSTEM INSTALLED PRIOR TO 1ST JUNE 2012			
Directly sold energy from the solar cells during incentive period	6130	0,5418	3320,96
Directly sold energy from the solar cells during the non-incentive period	6130	0,1386	849,53
Savings from load control	365	0,1505	54,92
PV SYSTEM INSTALLED AFTER 1ST JUNE 2012			
Directly sold energy from the solar cells during incentive period	6130	0,3471	2127,88
Directly sold energy from the solar cells during the non-incentive period	6130	0,1386	849,53
Savings from load control	365	0,1505	54,92

The financial parameters for the analysis have not been changed except the income tax which has been changed to 20%. Again, to estimate the profitability of the project, economic cash flow has been conducted with calculation of net present value. The results with photovoltaic system built before 1.6.2012. are given in the figure (Figure 6.2).

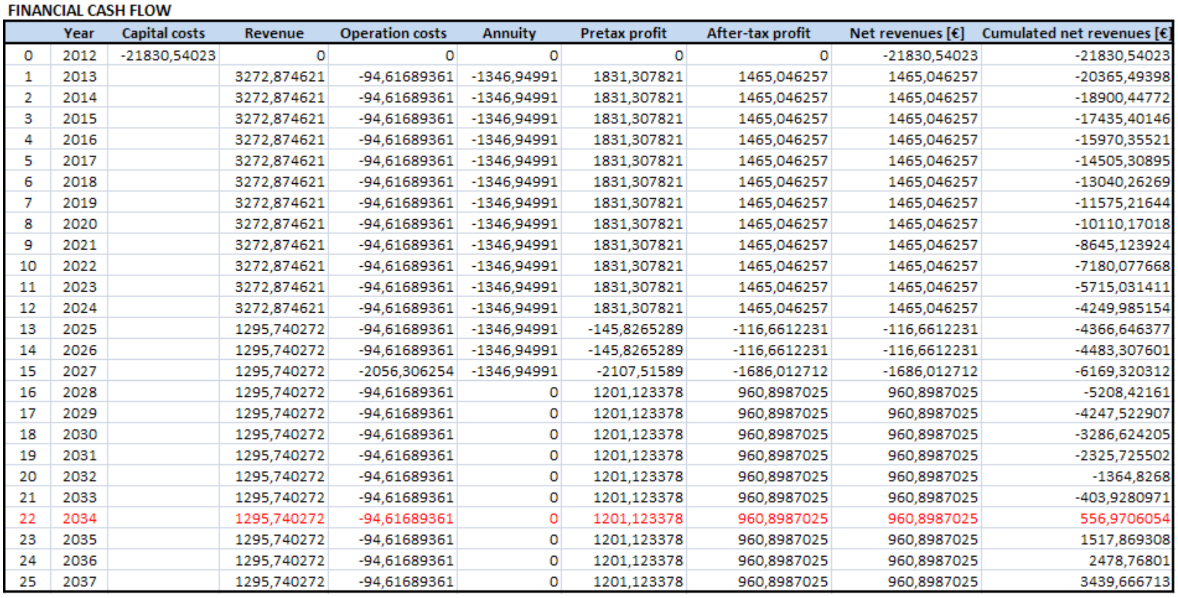


ECONOMIC CASH FLOW

	Year	Capital costs	Revenue	Operation costs	Pretax profit	After-tax profit	Net revenues [€]	Cumulated net revenues [€]
0	2012	-21830,54023	0	0	0	0	-21830,54023	-21830,54023
1	2013		3375,8725	-94,61689361	3281,255607	2625,004486	2625,004486	-19205,53575
2	2014		3375,8725	-94,61689361	3281,255607	2625,004486	2625,004486	-16580,53126
3	2015		3375,8725	-94,61689361	3281,255607	2625,004486	2625,004486	-13955,52678
4	2016		3375,8725	-94,61689361	3281,255607	2625,004486	2625,004486	-11330,52229
5	2017		3375,8725	-94,61689361	3281,255607	2625,004486	2625,004486	-8705,517806
6	2018		3375,8725	-94,61689361	3281,255607	2625,004486	2625,004486	-6080,513321
7	2019		3375,8725	-94,61689361	3281,255607	2625,004486	2625,004486	-3455,508835
8	2020		3375,8725	-94,61689361	3281,255607	2625,004486	2625,004486	-830,5043498
9	2021		3375,8725	-94,61689361	3281,255607	2625,004486	2625,004486	1794,500136
10	2022		3375,8725	-94,61689361	3281,255607	2625,004486	2625,004486	4419,504621
11	2023		3375,8725	-94,61689361	3281,255607	2625,004486	2625,004486	7044,509107
12	2024		3375,8725	-94,61689361	3281,255607	2625,004486	2625,004486	9669,513592
13	2025		904,4545635	-94,61689361	809,8376698	647,8701359	647,8701359	10317,38373
14	2026		904,4545635	-94,61689361	809,8376698	647,8701359	647,8701359	10965,25386
15	2027		904,4545635	-2056,306254	-1151,85169	-921,4813527	-921,4813527	10043,77251
16	2028		904,4545635	-94,61689361	809,8376698	647,8701359	647,8701359	10691,64265
17	2029		904,4545635	-94,61689361	809,8376698	647,8701359	647,8701359	11339,51278
18	2030		904,4545635	-94,61689361	809,8376698	647,8701359	647,8701359	11987,38292
19	2031		904,4545635	-94,61689361	809,8376698	647,8701359	647,8701359	12635,25305
20	2032		904,4545635	-94,61689361	809,8376698	647,8701359	647,8701359	13283,12319
21	2033		904,4545635	-94,61689361	809,8376698	647,8701359	647,8701359	13930,99333
22	2034		904,4545635	-94,61689361	809,8376698	647,8701359	647,8701359	14578,86346
23	2035		904,4545635	-94,61689361	809,8376698	647,8701359	647,8701359	15226,7336
24	2036		904,4545635	-94,61689361	809,8376698	647,8701359	647,8701359	15874,60373
25	2037		904,4545635	-94,61689361	809,8376698	647,8701359	647,8701359	16522,47387
							NPV	**2.238,27 €**
							IRR	**8%**
							Profitability index	**1,102529237**

Figure 6.2 Economic cash flow for a smart house in Croatia (PV system built before 1.6.2012)

It is clear from the figure that NPV is positive which means the project is profitable. Furthermore, internal rate of return and profitability index have been calculated and they support the conclusion that this is a profitable project. The payback period of the project is 9 years. In order to see the liquidity of the project, a financial cash flow has been made (Figure 6.3). It can be seen that the cumulated net revenues becomes positive in the 22nd year of the project.

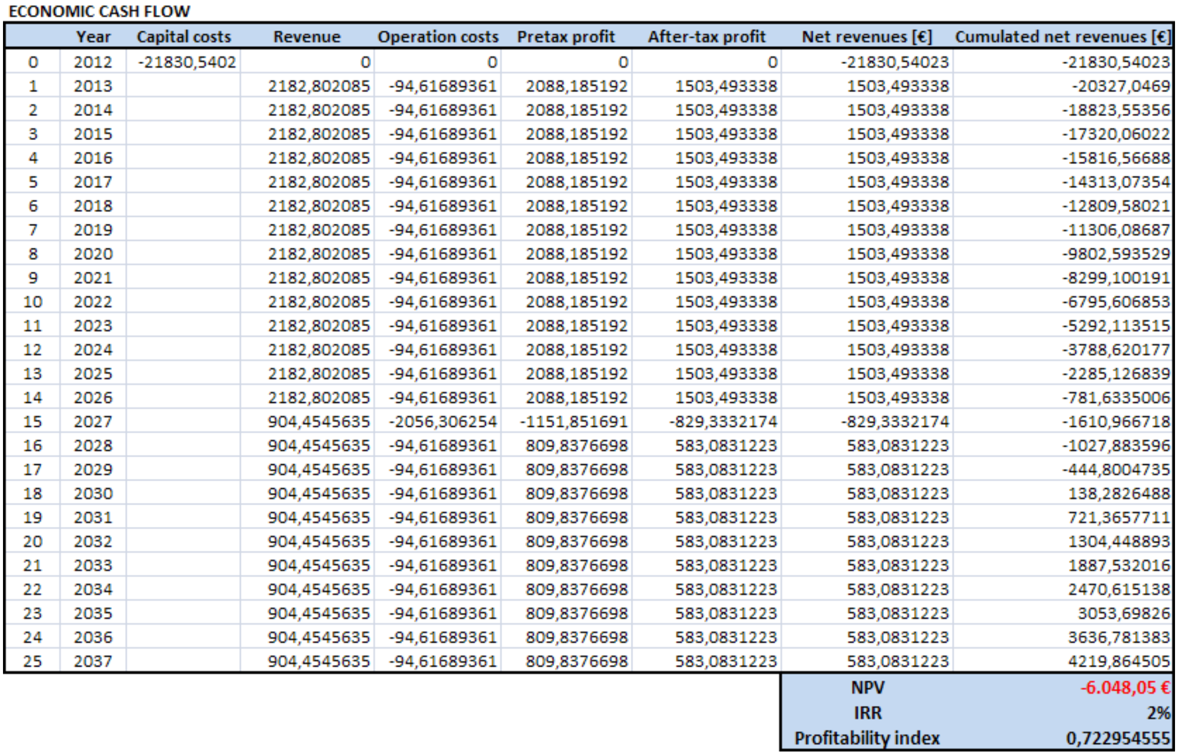


FINANCIAL CASH FLOW

	Year	Capital costs	Revenue	Operation costs	Annuity	Pretax profit	After-tax profit	Net revenues [€]	Cumulated net revenues [€]
0	2012	-21830,54023	0	0	0	0	0	-21830,54023	-21830,54023
1	2013		3272,874621	-94,61689361	-1346,94991	1831,307821	1465,046257	1465,046257	-20365,49398
2	2014		3272,874621	-94,61689361	-1346,94991	1831,307821	1465,046257	1465,046257	-18900,44772
3	2015		3272,874621	-94,61689361	-1346,94991	1831,307821	1465,046257	1465,046257	-17435,40146
4	2016		3272,874621	-94,61689361	-1346,94991	1831,307821	1465,046257	1465,046257	-15970,35521
5	2017		3272,874621	-94,61689361	-1346,94991	1831,307821	1465,046257	1465,046257	-14505,30895
6	2018		3272,874621	-94,61689361	-1346,94991	1831,307821	1465,046257	1465,046257	-13040,26269
7	2019		3272,874621	-94,61689361	-1346,94991	1831,307821	1465,046257	1465,046257	-11575,21644
8	2020		3272,874621	-94,61689361	-1346,94991	1831,307821	1465,046257	1465,046257	-10110,17018
9	2021		3272,874621	-94,61689361	-1346,94991	1831,307821	1465,046257	1465,046257	-8645,123924
10	2022		3272,874621	-94,61689361	-1346,94991	1831,307821	1465,046257	1465,046257	-7180,077668
11	2023		3272,874621	-94,61689361	-1346,94991	1831,307821	1465,046257	1465,046257	-5715,031411
12	2024		3272,874621	-94,61689361	-1346,94991	1831,307821	1465,046257	1465,046257	-4249,985154
13	2025		1295,740272	-94,61689361	-1346,94991	-145,8265289	-116,6612231	-116,6612231	-4366,646377
14	2026		1295,740272	-94,61689361	-1346,94991	-145,8265289	-116,6612231	-116,6612231	-4483,307601
15	2027		1295,740272	-2056,306254	-1346,94991	-2107,51589	-1686,012712	-1686,012712	-6169,320312
16	2028		1295,740272	-94,61689361	0	1201,123378	960,8987025	960,8987025	-5208,42161
17	2029		1295,740272	-94,61689361	0	1201,123378	960,8987025	960,8987025	-4247,522907
18	2030		1295,740272	-94,61689361	0	1201,123378	960,8987025	960,8987025	-3286,624205
19	2031		1295,740272	-94,61689361	0	1201,123378	960,8987025	960,8987025	-2325,725502
20	2032		1295,740272	-94,61689361	0	1201,123378	960,8987025	960,8987025	-1364,8268
21	2033		1295,740272	-94,61689361	0	1201,123378	960,8987025	960,8987025	-403,9280971
22	2034		1295,740272	-94,61689361	0	1201,123378	960,8987025	960,8987025	556,9706054
23	2035		1295,740272	-94,61689361	0	1201,123378	960,8987025	960,8987025	1517,869308
24	2036		1295,740272	-94,61689361	0	1201,123378	960,8987025	960,8987025	2478,76801
25	2037		1295,740272	-94,61689361	0	1201,123378	960,8987025	960,8987025	3439,666713

Figure 6.3 Financial cash flow for a smart house in Croatia (PV system built before 1.6.2012)

The economic cash flow in the case of the photovoltaic system installed after 1st June 2012 is given in the figure (Figure 6.4). As it can be seen, NPV is negative and profitability index is under 1 which means the project is not profitable. For NPV to become positive, the interest rate has to be less than 2% which is unrealistic to expect in today’s and future conditions.



ECONOMIC CASH FLOW

	Year	Capital costs	Revenue	Operation costs	Pretax profit	After-tax profit	Net revenues [€]	Cumulated net revenues [€]
0	2012	-21830,5402	0	0	0	0	-21830,54023	-21830,54023
1	2013		2182,802085	-94,61689361	2088,185192	1503,493338	1503,493338	-20327,0469
2	2014		2182,802085	-94,61689361	2088,185192	1503,493338	1503,493338	-18823,55356
3	2015		2182,802085	-94,61689361	2088,185192	1503,493338	1503,493338	-17320,06022
4	2016		2182,802085	-94,61689361	2088,185192	1503,493338	1503,493338	-15816,56688
5	2017		2182,802085	-94,61689361	2088,185192	1503,493338	1503,493338	-14313,07354
6	2018		2182,802085	-94,61689361	2088,185192	1503,493338	1503,493338	-12809,58021
7	2019		2182,802085	-94,61689361	2088,185192	1503,493338	1503,493338	-11306,08687
8	2020		2182,802085	-94,61689361	2088,185192	1503,493338	1503,493338	-9802,593529
9	2021		2182,802085	-94,61689361	2088,185192	1503,493338	1503,493338	-8299,100191
10	2022		2182,802085	-94,61689361	2088,185192	1503,493338	1503,493338	-6795,606853
11	2023		2182,802085	-94,61689361	2088,185192	1503,493338	1503,493338	-5292,113515
12	2024		2182,802085	-94,61689361	2088,185192	1503,493338	1503,493338	-3788,620177
13	2025		2182,802085	-94,61689361	2088,185192	1503,493338	1503,493338	-2285,126839
14	2026		2182,802085	-94,61689361	2088,185192	1503,493338	1503,493338	-781,6335006
15	2027		904,4545635	-2056,306254	-1151,851691	-829,3332174	-829,3332174	-1610,966718
16	2028		904,4545635	-94,61689361	809,8376698	583,0831223	583,0831223	-1027,883596
17	2029		904,4545635	-94,61689361	809,8376698	583,0831223	583,0831223	-444,8004735
18	2030		904,4545635	-94,61689361	809,8376698	583,0831223	583,0831223	138,2826488
19	2031		904,4545635	-94,61689361	809,8376698	583,0831223	583,0831223	721,3657711
20	2032		904,4545635	-94,61689361	809,8376698	583,0831223	583,0831223	1304,448893
21	2033		904,4545635	-94,61689361	809,8376698	583,0831223	583,0831223	1887,532016
22	2034		904,4545635	-94,61689361	809,8376698	583,0831223	583,0831223	2470,615138
23	2035		904,4545635	-94,61689361	809,8376698	583,0831223	583,0831223	3053,69826
24	2036		904,4545635	-94,61689361	809,8376698	583,0831223	583,0831223	3636,781383
25	2037		904,4545635	-94,61689361	809,8376698	583,0831223	583,0831223	4219,864505
							NPV	-6.048,05 €
							IRR	2%
							Profitability index	0,722954555

Figure 6.4 Economic cash flow for a smart house in Croatia (PV system built after 1.6.2012)

These two analysis lead to conclusion that the profitability of installing a smart house in Croatia is highly dependent on incentive prices for energy from renewable resources. In addition, even though current incentive prices are two times higher than electricity price, they are not big enough to cover high capital costs. Until the technology evolves and capital costs decrease, these kinds of projects will depend on the support from the Government.

7. Discussion of results

Simulated scenarios show behaviour of a smart house in different conditions. Basic theoretical assumptions for a smart house have been demonstrated on a concrete example.

It is clear that a renewable resource such as solar cells play a big role in functioning of a smart house. When solar energy is available, solar cells produce electricity that can be used in two ways – directly for reducing the amount of energy taken for the grid or charging the battery that will be used later if needed. Also, solar cells allow the user to stop being a passive consumer, and to produce and sell energy back to the grid to gain some profit.

Simulation results also support the theoretically described demand response principles. Smart appliances respond to signals that come from the distribution grid and by that participate in load clipping or other demand side management services. It is shown that the grid can limit the consumption of a smart house by direct control of specific appliances. However, this has to be approved by the customer because user's commodity must not be disturbed.

The energy storage in form of a battery can be used to supply the part of the consumption or to store energy and sell it in peak hours when the grid needs it. This also allows the smart house to participate in reserve and balancing energy market.

The conducted cost and benefit analysis shows profitability of implementing a smart house today. It is obtained that the implementation is not profitable today due to high capital costs. Nevertheless, people should not be discouraged by this result with regards to smart houses. In the past decade, the technology has rapidly evolved and many products that have been extremely expensive today are price acceptable to mass population. This is expected for the smart house components too which will encourage people in buying smart products. By introduction of new technologies in systems that have to be renovated anyway, such as buying a smart form of an appliance when in need of a new one, the Smart Grid will gradually expand and become fully operational at one point.

In addition, implementing smart houses has many benefits that do not have direct profit for the user itself, but influence the social welfare. For example, supporting the grid and selling the energy in peak hours optimise operation of the grid in such a way there is less need for bigger bunk generations. It is hard to add economic value to decreasing total energy consumption and CO_2 emissions, and consequently difficult to estimate total society benefits, especially when looking from the point of an individual customer. However, generally speaking, the society will surely profit from implementation of Smart Grid.

8. Conclusion

The existing power system is faced with many problems such as the lack of conventional resources and climate changes. With implementation of Smart Grid centralized production of energy will be moved to the place of consumption where every owner of a smart building will produce energy from renewable resources. This would reduce the need for large generating units and ensure more effective operation of the whole system. Furthermore, two-way communication will enable active interaction between smart houses and the system as well as two-way power flow.

In this paper a draft model of a smart house has been developed. Through various scenarios the importance of renewable resources in a smart house is clearly showed. The produced energy can be used in two ways – directly to supply part of the consumption or to charge the battery and use it later if needed. Simulations support theoretical assumption that renewable resource and energy storage change the passive consumer to an active part of the system. In addition, there have been conducted different scenarios to show demand response principles. Smart appliances respond to the signals from the grid and are turned off by energy management system in peak hours. This way the grid can limit total consumption of the house which helps in more efficient grid operation and long-term reducing of electricity market prices.

In the end, a cost and benefit analysis has been conducted for Norway and Croatia. It is obtained that implementation of smart house is not profitable today due to high capital costs, and that these kinds of projects are highly dependent on feed-in tariffs and other incentives. However, it is expected that the technology will evolve which will lead to reduction in capital costs and profitability of these projects. Therefore, it can be said that the prospects for smart buildings are big even though today they are somewhat exclusive. This means education has an important role. People have to be aware of its potential today because changing the whole system can not be carried out in a short period of time. When talking about sustainable future, smart houses and Smart Grid surely have an irreplaceable function. With the upcoming years, the Smart Grid era is yet to come.

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