SMART BUILDINGS

1 DEMAND-SIDE MANAGEMENT

1.1 INTRODUCTION TO SMART METERING AND SMART GRIDS

SMART METERING

Power meters are applied in the energy systems to measure the energy consumption. In these days, different kind of power meters are in use and they stand at different stages of development. The power meters could be divided into two main groups on the basis of their features and capability. The older type of power meters are the electromechanical meters. The development of these meters was necessary because of their limitations. For example, they are not able to serve very accurate results because some metering factors influence their measurement, they could be applied to measure only the basic energy components and human resources is needed for their reading. Because of the human factor, the possibility of error is higher and it increases the cost of energy as well. The newer type of power meters: electronic power meters serve more accurate energy measurement results and the price of energy could also be reduced with the help of remotely monitoring systems. For this remotely access, different technologies could be applied. Automated Meter Reading (AMR) AMR is able to ensure one direction information flow from the electronic power meters to the energy suppliers. On contrary, Advanced Metering Infrastructure (AMI) is already able to ensure two direction information flow between the electronic power meters and the energy suppliers. Lately, the term “smart meters” is used for electronic power meters, but there is no uniformed description what “smart” is. Smart meters have module structure, which provides the opportunity to get flexible measurement equipment, which has all the required features. Smart meters can measure not only the total consumption between the two reading periods but because of the remote access, the consumption of shorter terms as well. Thus, energy suppliers can examine the consumption data of their consumers, analyse their consumption behaviour, and they are able to develop their system and supply the energy more efficient. [1,2]

Smart metering technology provides the possibility for consumers to get real time information about their energy consumption. Therefore, they can modify their demand deliberately, they could take part in demand side management programs and they could reach energy and cost savings. The application of smart meters is advantageous for energy utility companies as well because with the help of them several information is available about the users. It offers a great opportunity to supervise and control the power grid, handle the consumption peak and off-peak periods and improve the security of energy supply. The collected data could help the development of new pricing methods, which lead to the reduction of the electricity consumption and the cost of energy. The more efficient energy supply leads to the reduction of energy production and harmful emission. With the help of smart meters renewable energy sources, new technologies and innovations are easier to integrate into the electricity system too. [1,2]

Despite of the fact that the usage of smart meters have several benefits, the social acceptance of them is not obvious. Studies tried to identify the influencing factors of public support. The main fundamental features of people is their demographic data, which are for example their age, their gender, their salary, etc. Based on researches, this information could be used to find the supportive group of people. Another group of factors could be the worries connected to the usage of personal information. Consumers have privacy concerns because with the help of the smart meters, the energy suppliers could get real time data about them and many people do not feel comfortable because of it. Moreover, people who suffered privacy violations before find the new technologies less favourable because of their previous experiences. Social norms could also influence the behaviour of people largely. People who like to adapt to each other prefer to behave how other people think they should or to behave how other people do. Therefore, these norms are also significant in the process of the acceptance of smart meter technology. Technology norms cover the positive and negative attitude of the people to smart meters. Optimism and the like of innovation could inspire people to accept them but feeling discomfort and insecure could withheld them. [3]

To regulate the electricity market, different standards have been developed and are in use. For example the International Electrotechnical Commission (IEC) with Technical Committee 13 (TC13) applied worldwide, the American National Standards Institute (ANSI) with ANSIC12 applied in North America, and European Standards were also created by the European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC). But in addition, some countries apply their own national standards and others combine different of them. [1]

SMART GRID

The first electrical power grids were settled in the 1800's but they were applied widely only from around 1960's. The energy needs were covered mainly by traditional sources: mainly fossil fuels, hydroelectric and nuclear energy sources were used. The energy demand grew significantly at the end of the 20th century. This energy need could not been served by the available energy sources, therefore new ones had to be integrated into the energy system. The energy production and consumption started to separate in time and therefore many efforts were taken to provide the balance between them. To handle the power system operation, Demand Side Management (DSM) methodologies were applied to influence the consumption of the consumers. [2]

The energy consumption continued to grow and the harmful emission caused by the generation was significant. To reduce the pollution while serve the required amount of energy, renewable energy sources needed to be integrated into the energy systems but the conventional grid was not able to handle that. New inventions were integrated into the power grid in the 21th century and Smart Grid system established. [2,4]

While conventional grid ensures information flow from power meters to utility companies and electrical energy from suppliers to users, smart grids can handle the whole energy system in efficient way using smart meters to ensure bidirectional communication and possibility for intervention. This helps not only the users to keep their homes and consumption under control but it also gives the opportunity for energy companies to manage the whole grid system: balancing the energy production and consumption; and distributing it in an appropriate way. Applying smart meters to supervise and control the energy system in real time, the security of supply could be increased and the energy losses could be decreased. Monitoring the energy flow through the electricity system, the input and output loads could be supervised and their impact to the behaviour of the energy system could be examined. [2,5]

Operating a smart grid system, a reliable, strong communication network has to be maintained between smart grid components. Several topologies, wired and wireless solutions could be applied. The most common short-range wireless technologies are Bluetooth, ZigBee and Wi-Fi. *Table 1.* includes the features of them. Wireless technology could also be used to cover larger areas: cellular networks could provide long distance connection with up to 100 Mbps bandwidth. As wired technology, Powerline Communication (PLC) and Digital Subscriber Line (DSL)/ Optical Fibre could be suitable. [2]

***Table 1*. Wireless communication technologies [2]**

Name	Range	Frequency	Bandwidth
Bluetooth	10 m	2,45 GHz	up to 3 Mbps
ZigBee	~100 m	868 MHz, 915 MHz, 2,4 GHz	20-250 kbps
Wi-Fi	up to 250 m	2,4 GHz, 5 GHz	up to 600 Mbps

The smart grid networks could be categorised into three main groups. The Home Area Networks (HANs) join the electric devices in one household and collect their consumption data with the help of smart meters. For this purpose technologies such as Bluetooth, ZigBee and Wi-Fi could be chosen. Neighbourhood Area Networks (NANs) collect the data of a limited areas and forward the data of smart meters to data collectors using technologies, like Wi-Fi. Wide Area Networks (WANs) connect the NANs and larger devices, and ensure the information flow from data collectors and devices to data centers. For this aim, for example cellular networks, optical fibre and power line communication technologies could be applied. [2]

To be able to maintain and develop the electricity systems, not only the existing conditions but also the future trends have to keep in mind. To reduce the damage of the nature, renewable energy sources have been integrated into the energy systems but the growing amount of them means challenge. The local energy production, the energy consumption and the energy fed into the grid change dynamically. Therefore, to ensure the balance between the supply and demand sides, the electricity system has to be monitored and supervised. The increasing number of the electric vehicles and their energy need also have to be taken account because the electricity grid should be able to supply them reliably too. To secure the proper operation of the energy system, to guarantee the appropriate information flow and to be able to use the advantages of the innovations, strong communication systems and energy grids are required. [6]

INTERNET OF THINGS

Several efforts were made to describe what Internet of Things (IoT) is but still, there is no standard definition for it. "In general, IoT is about a network of networks of uniquely identifiable endpoints or "things" that capture and share data." [7]

There is no uniformed architecture of IoT either but commonly it is divided into layers. The most widely applied architecture contains three layers: perception layer, network layer and application layer. The perception layer has a connection with the physical environment: it measures and collects data by applying sensors, actuators and other devices. The network layer secures the data flow between the perception and application layers. The application layer uses the data served by the other layers and keep in touch with the users through applications and their interfaces. [7,8]

***Table 2*. Architecture of Internet of Things** [7][8]

Perception Layer	Physical perception layer	Thing/device layer	Device layer	IoT sensing layer
Network Layer	Network layer	Connectivity layer	Connection layer	IoT network layer
Application Layer	Application layer	IoT cloud layer	Application layer	IoT application layer
Source	Yan et al. (2014)	Wortmann and Flüchter (2015)	Bandyopadhyay, Balamuralidhar, and Pal (2013)	Burrus (2014)

There are several types of IoT applications covering very different areas. Many studies are about grouping and ranking them. Transportation, energy, healthcare, smart homes, smart cities, financial services, information technology are some examples of the leading topics. IoT applications could be used for very different aims: they could be applied for example to monitor the patients in the healthcare system, to indicate the place of a leaking pipe in the water system, to control energy consumption in households, to help parking a vehicle or to monitor the quantity of available materials in a factory. [7,9]

As every innovation, IoT has advantages but disadvantages too. With the help of IoT, a huge amount of data is available and there is an endless possibility for their usage. It could improve the quality of life and could facilitate to manage processes. Otherwise, to build out an IoT system not only financial investigation is required but a well-trained stuff as well. Several difficulties could arise during the development and the operation of these IoT systems, and because of the complexity of them and the lack of experience it could be challenging to handle. [7]

1.2 INTRODUCTION TO DEMAND-SIDE MANAGEMENT (DSM)

To be able to supply the growing energy needs in an environmentally friendly and quality way, the development of the electricity system and the integration of new inventions are necessary. To serve the energy demand while reducing the harmful emission, renewable energy sources and energy storages are integrated into the energy systems. In the pursuance of the energy service development, the growth of the security of supply and the maintenance of balance between generation and consumption are also required. [6]

DEMAND SIDE MANAGEMENT

There are two possibilities to keep the balance between the increasing energy demand and the available energy generation capacity: the supply or the demand side should be set to the other one. Using demand side management (DSM) methodologies, the energy consumption of the demand side is influenced to assimilate to the energy production of the supply side. Applying DSM, the consumers should be motivated to modify their energy consumption, which could lead to aware and efficient energy usage, and therefore the energy losses and the harmful emission could also be reduced. [10,11]

The term “demand side management” was used first in 1984, created by Clark W. Gellings. “DSM activities are those which involve actions on the demand (i.e. customer) side of the electric metre, either directly or indirectly stimulated by the utility. These activities include those commonly called load management, strategic conservation, electrification, strategic growth or deliberately increased market share.” It is important to highlight, that DSM could be used not only for managing the electricity demand but also for handling the non-electric energy flow. [10,11]

The methodology of DSM was used before it became part of national acts. For example in the 1960's-1970's in New Zealand and Europe, DSM related actions were performed. DSM was included in a national policy first in the USA. It was presented in the National Energy Conservation Policy Act and Public Utility Regulatory Policy Act (PURPA) as parts of National Energy Act 1978. The oil embargo in 1970' led to energy crisis, the cost of energy increased significantly. To be able to handle the energy shortage, several efforts were taken in the USA, including the development of Integrated Resources Planning (IRP) by PURPA. The aim of it was to create strategies to be able to utilise the available energy sources and to serve the energy consumers in a cost-effective way. In the USA therefore, the DSM strategies became very popular. On the contrary in Europe: however in the 1980's the energy related problems was in the focus of political interest, because of the measures in the 1990's, most of the energy utilities were not motivated to deal with DSM. In the 2000's-2010's, the climate change and the security of energy supply got in the middle of attention and the DSM methodologies became popular worldwide. [11,12]

To ensure the proper operation of the energy system, the balance between the energy generation and the energy consumption have to be maintained. The energy generation changes dynamically during the day because of the integrated renewable energy sources, which production couldn't be forecasted accurately or controlled. The surplus generated energy should be consumed or stored but the problem of efficient energy storage hasn't been solved. To be able to serve the required amount of energy during the peak times reliably, plus resources should be integrated into the energy system, which resources work by fossil fuels. The availability of these extra assets would increase the cost of energy. To be able to ensure the security of energy supply, all parts of the energy system have to be dimensioned to the peak demands. The higher the peak demand is, the costlier the needed facilities and the energy generation are. Therefore, to decrease the cost of energy, the energy consumption of the consumers has to be controlled. They should be motivated to reduce their peak demand or to shift part of it to off-peak times, or to adapt to the energy generation. To ensure the possibility for consumers to react to the changes of energy generation, they should get accurate information about the current state of the energy system. The favourable situation is if energy consumption increases when renewable energy is available, and decreases during the peak times. [13]

To balance the energy generation and energy consumption two strategies are used in DSM: consumption reduction and efficiency improvement. Based on these strategies, DSM techniques could be categorised into two modalities: static DSM (SDSM) and dynamic DSM (DDSM). First, the general DSM techniques are presented, which are the electric load management (ELM) and energy conservation (ENCON). [10]

Table 2. **DSM methods [10]**

		Techniques	
Strategies	**Modalities**	Electrical load management	Energy conservation
Consumption reduction	Static DSM	*SELM*	*SENCON*
Efficiency improvement	Dynamic DSM	*DELM*	*DENCON*

The aim of ELM is to change the electricity consumption profile of consumers and it has two modalities according to the applied strategies: static ELM (SELM) and dynamic ELM (DELM). The SELM aims to decrease the energy consumption by this energy usage modification. In contrast, the aim of DELM is to change the load shape to reach higher effectiveness in energy usage. SELM applies Strategic Conservation and Flexible Load Shape techniques; DELM applies Peak Clipping, Valley Filling, Load Shifting and Strategic Load Growth techniques. The load shaping techniques of ELM could be seen in Figure 1. Strategic conservation is used for decreasing the energy consumption in general, Flexible Load Shape is used for modifying the energy needs of consumers according to the available energy. Peak Clipping is used for decreasing the energy consumption during the peak time, Valley Filling is used for increasing the energy consumption during the off-peak time, Load Shifting is used for shifting the energy consumption from peak time to off-peak time and Strategic Load Growth is used for increasing the energy consumption. Peak Clipping, Valley Filling and Load Shifting techniques are applied to flatten the load curve and decrease the fluctuation of energy consumption. Strategic Load Growth technique is applied to increase the efficiency of system operation. [10]

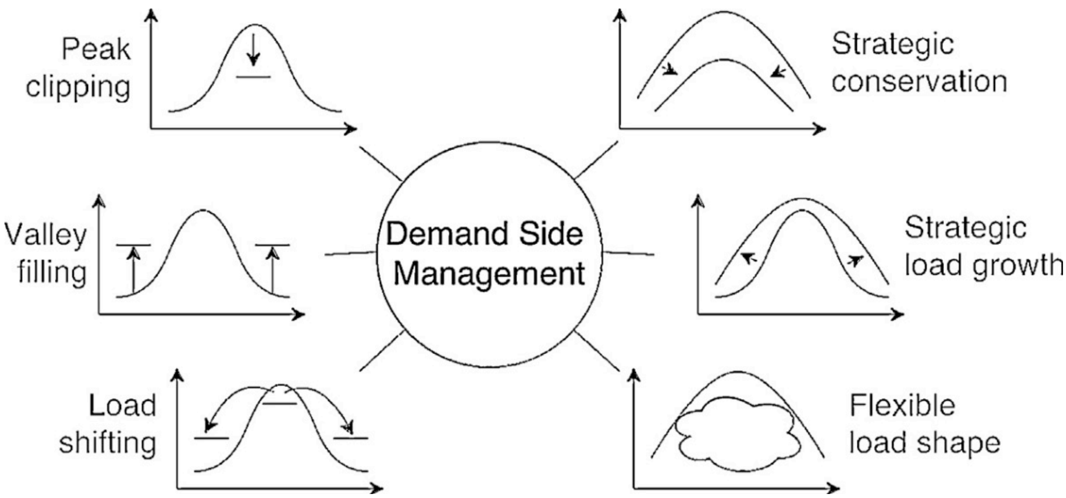

Figure 1. "Basic load shaping techniques (Gellings, 1985)" [13]

The aim of ENCON is to reduce the energy losses. To be able to describe the ENCON techniques, first, the scheme of the energy flow through the energy system should be introduced. The input energy flow is the terminal energy, which is "the energy which is available to use after subtraction of distribution losses and quantities stored". The output energy flow is the useful energy, which is "the required energy for doing work". Their difference is the energy loss. The energy efficiency is the ratio of the useful and the terminal energies. Based on these characteristics, three different ENCON mechanisms could be identified. The aim of Energy Recovery mechanism is to reduce energy losses, while terminal energy is fix. Therefore, useful energy and energy efficiency increase (for example: using combined heat and power plans). The aim of Energy Audit mechanism is to reduce energy losses while useful energy is fix. Therefore, terminal energy decreases, energy efficiency increases (for example: using thermal insulations on the buildings). The aim of Energy Saving mechanism is to reduce energy losses, while energy efficiency is fix. Therefore, terminal energy and useful energy decrease (for example: modifying the lighting system). In accordance with the above, two ENCON strategies exist: Energy Consumption Management (ECM) and Energy Efficiency Management (EEM), which control the terminal energy and energy efficiency, respectively. ENCON also has two modalities: static ENCON (SENCON) and dynamic ENCON (DENCON). While SENCON uses ECM mechanisms (Energy Audit, Energy Saving), DENCON uses EEM type of mechanisms (Energy Audit, Energy Recovery). [10]

As it mentioned before, the DSM techniques could be categorised into SDSM and DDSM modalities according to their characteristics. SDSM methods are the SELM and SENCON, focusing on the possibilities of energy consumption control, DDSM methods are the DELM and DENCON, focusing on the possibilities of energy efficiency control. SDSM methods aim to modify the energy consumption of the consumers by motivating them to regulate their energy usage and change their load profile. The success of these methods depends on the behaviour of the clients because their participation and cooperation is voluntary. Using DDSM methods, the energy consumers are obligated to take part in the energy regulation process to improve the efficiency of the energy system and they are active part of the energy control system. [10]

DELM methods could be categorised into two basic types: Orderly Power Utilisation (OPU), which is the "nonmarket-based DELM" and Demand Response (DR), which is "market-based DELM". The reason of these names is that while OPU applies administrative measures to reach the aim of DELM, DR applies market measures for the same reason. OPU is "the regulation of load demand by adopting administrative, economic, technological and other measures which lead clients to effectively utilize electricity via guarantee in critical condition such as power supply shortage or when reliability is jeopardized". There are three types of OPU: Strategic Saving, Strategic Productivity and Strategic Transfusion. Strategic Saving uses Peak-Clipping and Strategic Conservation mechanisms to reduce the energy load during the required time period. Strategic Productivity uses Load Shifting and Flexible Load Shape mechanisms to modify the shape of the load profile while the amount of used energy is stable. Strategic Transfusion uses Valley Filling and Strategic Load Growth mechanisms to increase the energy load during the required time period. DR is “alternations in electricity usage of customers from their usual consumption patterns in response to changes in the electricity price, or in response to incentives designed to influence electricity utilization at critical times characterized by high wholesale market prices or when the reliability is imperilled”. Applying DR methods, the customers are motivated to take part in the regulation of the electricity system and to modify their energy usage by offering them cost reduction options. In the energy service, without DR programs fix energy prices are used, which does not inspire the customers to cooperate. Using DR programs, the energy prices fluctuate reflecting to the state of the energy system and to the costs of generation, which leads to the appropriate end-user behaviour. [10]

1.3 INTRODUCTION TO DEMAND RESPONSE

The aim of demand response (DR) is to change the energy consumption behaviour on the demand side according to the electricity generation and the cost of the service. Consumers who take part in DR programs can act different ways. They can decrease their consumption during peak times and do not change their consumption during off-peak times, therefore save energy and money at the expense of their comfort. They can decrease their consumption during peak times and increase their consumption during off-peak times, therefore consume the same amount of energy with different distribution. They can utilize their own energy generation sources and decrease the demand on the common grid. [13]

There are several DR methods and they could be categorised into sub groups. The characteristics of these methods are in the following list and the taxonomy of DR can be seen on Figure 2. [10]

- DR methods without dispatch capability aim to motivate the demand side to change the energy consumption profile and reduce the electricity load during the peak times by using different tariffs for different time periods according to the cost of generation. Applying these methods, there is no possibility for suppliers to reduce the energy consumption of their consumers, they always have to serve the required amount of energy. [10]
    - Real time pricing (RTP) method aims to change the consumption behaviour of consumers by applying real time energy prices, which are determined based on the actual generation cost of electricity. The clients are motivated to reduce their energy load during the peak periods and shift it to the off-peak periods because of the hourly changing energy prices. [10]
    - Time of use tariff (TOU) method uses similar strategy like RTP but it divides the time periods into smaller blocks and determine different energy prices for each ones according to the average cost of energy supply during the given blocks. The lower prices during off-peak periods, higher prices during peak period and moderate prices during the time periods between could reflect the changes of the energy system. [10]

        - Critical peak pricing (CPP) method focuses on the critical peak periods. High energy prices are determined for these critical periods to motivate the customers to reduce their consumption during these times. Not only high peak period tariffs are used, but participants are also got rebate during the non-critical peak periods. [10]
            - Fixed period critical peak pricing (FP-CPP) method maximises the number and the length of time periods when the customers can participate and they are notified about critical peak times on the previous day. [10]
            - Critical peak rebates (CPR) method applies fix prices for different time periods and rebate is given to consumers, who decrease their energy consumption during critical peak periods. [10]
- DR methods with dispatch capability use "financial incentives and special market mechanisms so that the demand-side resources will be incorporated into power system operation". [10]
    - DR programs with reliability scope aims to increase the reliability of the energy system by increasing the range of options available to system operator. [10]
        - Available demand-side resource capacity control (ADSRCC) methods empower the system operator to control the demand side resources. [10]
            - Direct ADSRCC has two types: Technological Direct Load Control and Direct Control Through Capacity Markets. [10]
                - Technological Direct Load Control (TDLC) method functions in a way, that the system operator can control the energy consumption of the demand side by remotely switching on/off certain electric devices or modifying their operation to maintain the balance between the energy generation and consumption. Take part in TDLC programs is voluntary but the cooperation is compulsory. [10]
                - Direct control though capacity markets method doesn't give controlling possibility for system operator over the electric devices of the demand side. The energy utilities and energy consumers, who are able to reduce their energy usage when it is required, can participate in the system operation. For taking part in this program and being at service, they get incentives, called Capacity Payments. Most of the time, there is no need for energy load reduction but if the participants are warned to decrease their consumption and they are not cooperate, they are penalised. If they cooperate during these periods, they get more incentives. [10]

- Indirect ADSRCC also has two types: Contractual Indirect Load Control and Indirect Load Control via CPP. [10]
    - Contractual indirect load control (CILC) method could be applied voluntary. The participants take part in the control of the energy system by reducing their own energy load when it is ordered by the utility. Their cooperation is compulsory. If they cooperate during the required periods, they get incentives. If they do not cooperate, they are penalized. [10]
    - Indirect control via CPP method functions such a way, that the energy consumption alteration is done automatically according to the critical peak prices. [10]
        - Variable period CPP (VP-CPP) method does not predetermine the date and the length of the critical periods. [10]
        - Variable peak pricing (V-PP) method does not predetermine the energy price of critical peak periods because it is calculated according to the actual energy prices. [10]
- Voluntary response programs provide the opportunity to take part in the regulation process of the energy system voluntary. Participants can decide freely if they reduce their energy usage during the required time periods. If they cooperate, they get incentives. If they do not, they do not have to pay penalty. [10]
- Available demand-side reserve management (ADSRM) programs provide the opportunity to customers to take part in energy system regulation by controlling their own swift response capacity. This capacity appears as non-spinning reserve resource in the energy system and the participants are paid because of their availability. If the clients cooperate when the system operator orders it, they are rewarded. [10]

- DR programs with economic scope give economic incentive to clients to change their energy consumption behaviour. Applying these programs, the consumers can sell a part of their own purchased energy. There are two types of implementation. One of the options is, that the retailers make a bid about the energy load reduction capacity to the market operator and if it is accepted, the fulfilment is compulsory. The consumers are warned, and those who reduce their consumption are rewarded according to the market clearing price. The other option is, that utility determine a reference price and the customers can decide how much they would reduce their energy consumption. If the bid is accepted, the consumption reduction is compulsory. If they do not cooperate, they have to pay penalty. [10]

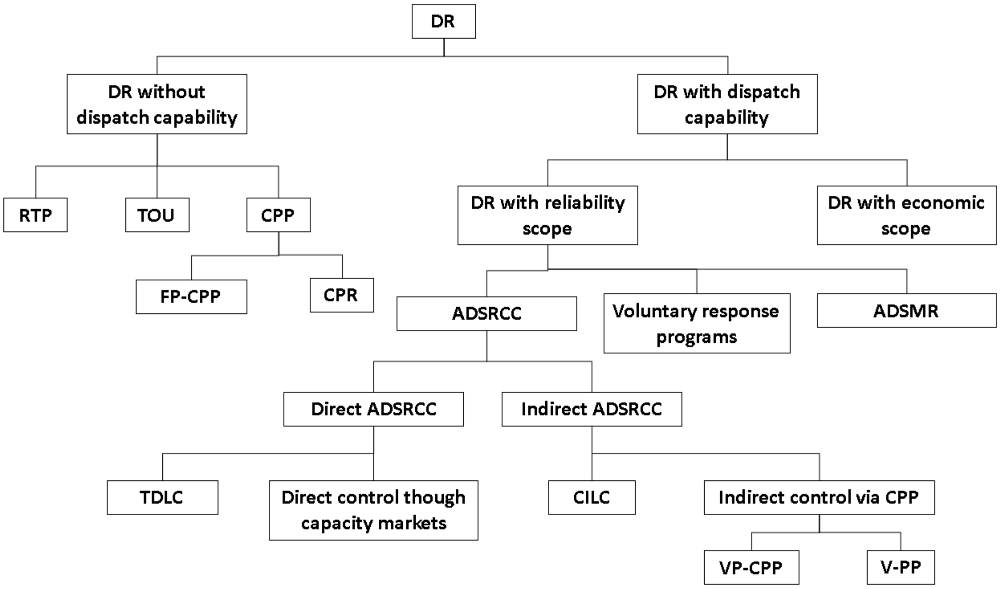

Figure 2. Taxonomy of DR [10]

1.4 ENERGY-RELATED OCCUPANT BEHAVIOUR IN BUILDINGS

In recent years, both legislative instruments and market demand drive the construction industry towards high-performing, low-energy consuming buildings [14,15]. However, without considering the human dimension, technologies alone do not necessarily guarantee high performance in buildings [16,17]. Occupant behaviour is a leading factor influencing energy use in buildings [18]. Occupant behaviour in buildings primarily refers to occupants' comfort preferences, presence and movement, and adaptive interactions with building systems that have an impact on the performance of buildings (e.g., thermal, visual and acoustic comfort provision; indoor air quality; energy use). Such interactions include adjusting thermostat settings, opening or closing windows, dimming or turning on/off lights, pulling up or down window shades and blinds, switching on or off plug loads, and consuming domestic hot water. [19]

To represent our buildings' energy balance and indoor environmental conditions and also to lower the energy consumption of buildings, the use of building performance simulation (BPS) tools is essential in the design process in case of both new construction and retrofitting projects [20]. There is a performance gap observed between real and predicted energy consumption of buildings. The core issues are not with deterministic factors, such as the physical characteristics of building envelope, HVAC systems, lighting and electrical equipment, which have been investigated for the past few decades. Rather, this gap was found to be mostly caused by over-simplifying occupants' behaviour and presence patterns in buildings during the design process [19,20].

Concept of Occupant Behaviour [21]

The concept of energy-related occupant behaviour in buildings can be defined as occupants' behavioural responses to discomfort, presence and movement, and interactions with building systems that have an impact on the performance (energy, thermal, visual, and IAQ) of buildings [22]. The interactions under investigation in this work include adjusting thermostat settings, opening or closing windows, dimming or turning lights on/off, pulling window blinds up or down, and switching plug loads on or off [23]. Energy-related occupant behaviour in buildings is one of the six influencing factors of building performance [24,25], which also includes climate, building envelope, building equipment, operation and maintenance, and indoor environmental conditions. Occupants can influence the indoor thermal and air condition directly by their mere presence (emitting heat, moisture and CO_2), or indirectly through their interactions with building systems. [19]

Multidisciplinary Nature of the Field

In this section a brief overview is given about the different fields dealing with energy-related occupant behaviour and their focus of research.

Currently, according to the literature and as seen above, building energy professionals make an assumption that all energy-related actions of occupants (window opening, blind closing, thermostat adjustment) are undertaken to restore comfortable indoor conditions. After simplifying the decision-making part, researchers had a closer look at the actions themselves and their effect on the indoor environment and the energy consumption of the building.

Whereas, researchers in social science apply another approach where the focus is on the psychological and social aspects of the decision making. Influencing factors and attitudes are determined that may influence the undertaking of a certain action. The effect of the actions are investigated in a broader dimension in general.

The main difference of these two approaches lays in the difference of aspects and phase of energy-related human behaviour under the microscope.

1.5 TOOLS FOR INVESTIGATION OF OCCUPANT BEHAVIOUR IN BUILDINGS

The different tools that can help to understand and investigate energy-related occupant behaviour in buildings, can be categorized according to the following subsections.

Questionnaires (Longitudinal or transversal), Interviews

It is often the case when investigating occupant behaviour in buildings that objective measurement data are not available or not understandable on its own. In these cases questionnaire surveys and interviews are useful tools to complement an existing dataset or even to get new knowledge on a larger sample in a poorly researched area.

Walk-throughs

It is essential before starting the investigation in any buildings, that the team conduct an onsite walk-through when all the available control features are listed and also accessibility and usability of the features are tested. These walk-throughs are usually supplemented with on-site personnel interviews with building operators, maintenance staff, building owners, tenant representatives, etc.

Occupancy data

If possible, time-series data should be collected in case of all occupant-related investigations. These datasets can be collected in several ways (BMS system data, infrared sensor data, entrance counting door sensors, etc.) and datasets can be two types: containing occupancy data only as either occupied or not for a room, or exact number of occupants staying in a given room.

BMS data

Most new or retrofitted buildings are equipped with building management systems that record data for the building which can contain information on energy use and also occupant behaviour. Datapoints that are usually useful to investigate:

- fresh air amount for ventilation,
- fan coil valve status,
- heat, gas, electricity submetering,
- water submetering.

1.6 USER ENGAGEMENT TOOLS OF DSM

There are many ways to engage building occupant to decrease their consumption. One way of categorizing these tools are as follows:

- Indirect information sources
- Education and training
- Instant feedback systems
- Training and gamification tools
- Financial incentives
- Competitions and social media

In the following list of examples, some key tools and interesting example projects [26] are introduced to serve as a guideline for readers.

A. PUBLIC DISPLAY OF ENERGY AUDITS

In case of public buildings, building energy audits are often conducted. These are supposed to contain recommendations for improving the energy performance of the building – including technical measures that may be implemented at zero or very low cost and organizational improvements, including the active participation of users by adopting a set of behavioural changes.

To the purpose of spreading awareness about the current situation and the prospective targets of improvement, easily understandable infographics can be created mirroring the structure of the Energy Performance Certificates (EPCs).

B. SIMPLIFIED MESSAGING

For different age classes, simplified or more detailed messages can be designed and conveyed as fit to the purpose, and put on display like proxies of more descriptive presentations of any public building's energy performance.

The above tool has already been validated by the TOGETHER partners during an earlier stage of the project. Therefore, its pilot implementation can follow a slightly different process than the other tools proposed, namely:

C. THE EURONET 50/50 MAX PROJECT METHODOLOGY AND E-PACK[1]

The EU funded project named EURONET 50/50 MAX ideated and successfully deployed a 9-step methodology (Figure 3) to actively involve occupants in the energy efficiency management of buildings and teach them how to behave in a more environmentally friendly way through practical actions.

[1] Source: http://www.euronet50-50max.eu/en/about-euronet-50-50-max/the-50-50-methodology-9-steps-towards-energy-savings

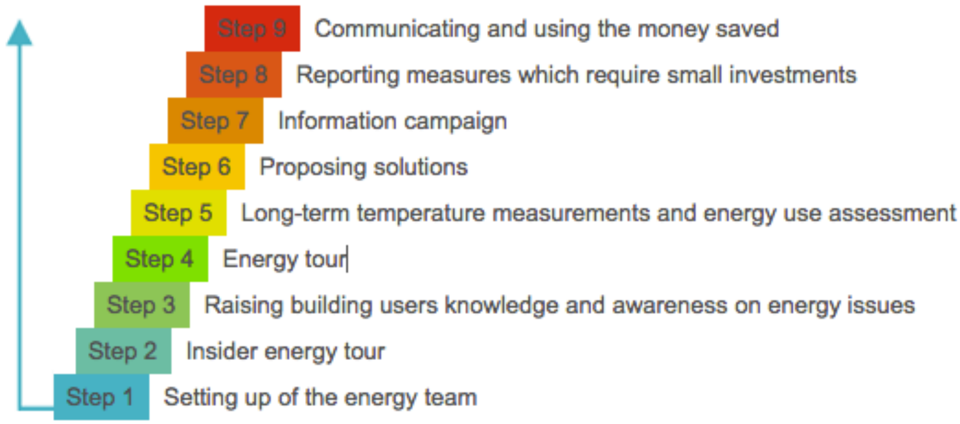

Figure 3. 9-step methodology of EURONET 50/50 MAX

D. SETTING UP AN ENERGY TEAM

Consisting of a group of occupants. Its task is to explore the current energy situation of the building and to propose and implement energy saving measures. The team would also organize an information & education campaign addressed to the rest of the building's community.

E. ORGANISING AN INSIDER ENERGY TOUR

Before starting to work with the occupants, the director together with involved energy operators should take part in a so called "Insider energy tour" aiming to do an initial assessment of the energy characteristics of the building (including assessment of the heating system, technical state of the building, etc.) and to identify the elements, to which occupants' attention should be drawn.

F. RAISING THE OCCUPANTS' KNOWLEDGE AND AWARENESS ON ENERGY ISSUES

A set of training sessions (during regular classes and additional meetings if possible) about such topics as: forms of energy, using energy in everyday life and its impact on the environment, greenhouse effect, climate change and climate protection, energy saving, energy efficiency, use of renewable energy sources. The aim is to raise knowledge and awareness of issues related to climate and energy, as well as to make occupants aware that there are opportunities to do something about climate change and that their individual actions do matter.

G. OCCUPANTS' ENERGY TOUR

This time the energy tour is made by the energy team. Supported by the operators and caretaker, the occupants inspect the whole building and evaluate different aspects influencing the energy consumption in the building, including: technical state of the building, heating system, lighting, use of electronic equipment, use of water.

H. LONG-TERM TEMPERATURE MEASUREMENTS AND ENERGY USE ASSESSMENT

Drawing up a long-term temperature profile of the building by measuring temperatures in all building rooms for two weeks and checking if they correspond to the established standards.

Assessing energy use based on observing how other building users' behaviour influences the energy consumption in the building. Special attention should be paid to such behaviour as: methods of airing the rooms, methods of regulating the heating, the use of electrical and electronic equipment, etc. Surveys can be made among other occupants (outside the energy team) regarding their opinions about temperatures and air quality in the building, habits concerning the use of electrical and electronic equipment and other energy-related issues.

I. PROPOSING SOLUTIONS

At this step the energy team discusses its findings and develops proposals for solutions, both small investments and behavioural changes, the implementation of which may reduce energy consumption at the building. The team also identifies proposal "target groups", as well as ways to approach them with the energy-saving message.

J. INFORMATION CAMPAIGN

At this step the energy team shares what was learned during project implementation with the rest of the building, as well as their proposals on what all building users can do to save energy. The team may use different communication channels, including: posters and bulletin board displays, presentations in training sessions, organization of an Energy Saving Day, creation of a dedicated website, etc.

K. REPORTING MEASURES WHICH REQUIRE SMALL INVESTMENTS

Although the main aim of the 50/50 methodology are energy savings that can be achieved by changing the behaviours of building users, the energy team can also identify the need and propose the implementation of small investments, asking for the financial support of the building owner and/or external sponsors.

L. COMMUNICATING AND USING THE MONEY SAVED

Involving the occupants in the decision on how to use the money saved is a very important part of the methodology. By so doing they will really feel that their actions have positive and measurable results. Therefore, after each year of implementation it is required to calculate how much energy, CO_2 and money was saved, inform the building's community of the financial inflows derived from the methodology implementation and discuss with the occupants what shall be done with those gains.

M. TRAINING OF TRAINERS

The Training of Trainers process is well consolidated and widely adopted in the state of the art.

The essence of the Training of Trainers process is to integrate coaching and mentoring with training and technical assistance to learners.

N. DISCOVERING THE ENERGY EFFICIENCY LABELS OF APPLIANCES

Energy Star is an international standard programme for energy efficient consumer products originated in the United States in 1992 and adopted in most Western countries such as Australia, Canada, Japan, New Zealand, Taiwan, and the EU.

Devices carrying the Energy Star blue mark, such as computer products and peripherals, kitchen appliances, refrigerators and dryers, generally use 20–30% less energy than the average level required by law[2]. The EU Directive 92/75/EC, replaced by Directive 2010/30/EU, in operation since 31st July 2011, has established an energy consumption labelling scheme for white goods, light bulbs and other heterogeneous products, based on a set of energy efficiency classes ranging from A to G, A being the most energy efficient, G the least efficient. Since 2010, in an attempt to keep up with advances in energy efficiency, A+, A++ and A+++ grades were introduced and a new type of label exists that makes use of pictograms rather than words, as shown in the picture[3]. The (now closed) EU funded project COME ON LABELS (see http://www.come-on-labels.eu/about-the-project/welcome-eu) has produced a dedicated website to store and distribute information on energy labelling of household appliances. The web application http://eepf-energylabelgenerator.eu/ enables the creation of tailor-made energy labels for relevant products in high resolution pdf format.

Depending on the age of participants, the discovery process can be done at different levels: finding out which appliances bear which labels, understanding the meaning of the

[2] Source: https://en.wikipedia.org/wiki/Energy_Star
[3] Source: https://en.wikipedia.org/wiki/European_Union_energy_label

pictograms on each label, displaying larger sized labels in the areas where each appliance is located.

O. THE GREAT POWER BINGO!

This game is particularly suitable for young kids, but can also be adapted to teen agers and probably adults – in dependence of the complexity of the challenges.

How it works: Every player will receive a bingo card with the usual random numbers displayed on it. Each number (from 1 to 70 in the example displayed, but this may be changed accordingly) is associated to a certain behaviour that one intends to promote in the target population. The player can mark a number on the card only after checking that someone else, not depending on his/her will or orders, has accomplished a specific task holding that number (for instance, 51 is turning the light off when leaving the room, 54 is closing a window left open with the heating on, etc.).

Each behaviour must be recorded (date, time, person) in order for the mark to be valid. Players win every time they can mark a straight line of five numbers either horizontally, vertically or diagonally. The global target is to cover all the numbers on the card.

There will be a raffle periodically (e.g. every month) for the assignment of low category prizes to those who have marked one or more lines of 5 and for the extraction of the free number, which may be different from month to month. Whoever completes the card first will be the winner of the bingo game.

P. THE ENERGY CONSUMPTION ANALYZER (ECAS) APP (ONLY FOR ANDROID)

ECAS has been developed by an Austrian developer as a free and open source software, with translations available[4].

How it works: ECAS helps to keep track of energy consumption of any building. Users can add meters for gas, electricity, or water to the database and record the current meter readings from time to time.

Readings can be color-coded and comments may be added to remember special situations, which may explain unusual energy usage. A regular reading interval is not required, readings can be taken whenever it is convenient.

ECAS takes advantage of Google's backup and restore service, so the database is automatically stored in a safe place in case the device is reset or lost. On the other hand, ECAS does not track changes of energy cost over time. Whatever costs are set in the meter definition are used for the entire set of readings. Changing the cost factor for a meter

[4] Source: http://ecas.netzheimat.at/

immediately changes the readings for the energy cost of that meter. Finally, the product is not supported for iOS or Microsoft devices.

Beside the convenience of being available in many different languages, the rationale of using this tool is that it allows unsystematic collections and updates of meter readings, which is the most likely usage scenario in all the pilot buildings. As a side benefit, users can consider gas and water consumption jointly with electricity, so as to get a unitary view of the current status of the building's energy efficiency across time. In the case of pilots located in buildings, the benefit of using this tool is evident from the fact that the occupants could be periodically invited to check and monitor the impact of their activities in the pilot by directly addressing the information made centrally available in the database of meter readings. Finally, a global advantage for the project coming from a generalized use of the tool would be that the progress gained in terms of energy reduction during pilot implementations could also be measured at regular intervals.

Q. THE GOOSECHASE APP (FOR ANDROID AND IOS)

GooseChase has been created to simplify the organization of and participation in a scavenger hunt. The app and its related service are delivered by a Canadian company[5].

How it works: The customer uses the GooseChase website to first create a challenge, by giving it a name, a picture and a description. One can also set how long the game will run and whether there is a password to join. Each GooseChase challenge includes a list of missions for the participants to complete. One can design missions from scratch. Every mission has a name, a description, value in points and an optional link to provide extra information. It is possible to add GPS coordinates to the mission locations.

Participants get access to the challenge by searching for the name of the game within the app. They select a mission from the list and follow the instructions to receive the allotted points. They are also invited to provide real-time feeds of their activities, in order to get more points and go up in the ranking. But they are also incentivized to look at what the others are doing, because this also gives them some extra points.

It is possible to form teams or play individually. Submissions are possible of texts, photos and videos, which can be sorted out and reviewed by the organizers in case scores have to be assigned after evaluation. At the end of the game, all scavenger hunt submissions can be downloaded at once by the customer.

The rationale of using the scavenger hunt analogy is to give incentives to report back on the actual behavioral performance of participants in the "game", as well as on the level of awareness of the results obtained on the fly. For instance, behaviors to be incentivized may include the daily inspection of the information available on energy consumption (by smart

[5] Source: https://www.goosechase.com/terms-of-service/

meters, big displays, or other sources that the general public may get access to), which will be proven by taking a picture and uploading it to the system. Or it is possible that the last person to turn the light off in a room will take a picture of the room itself to demonstrate achievement.

1.7 REFERENCES

[1] F.D. Garcia, F.P. Marafao, W.A. De Souza, L.C.P. Da Silva, Power Metering: History and Future Trends, IEEE Green Technol. Conf. (2017) 26–33. https://doi.org/10.1109/GreenTech.2017.10.

[2] D.B. Avancini, J.J.P.C. Rodrigues, S.G.B. Martins, R.A.L. Rabêlo, J. Al-Muhtadi, P. Solic, Energy meters evolution in smart grids: A review, J. Clean. Prod. 217 (2019) 702–715. https://doi.org/10.1016/j.jclepro.2019.01.229.

[3] J.D. Hmielowski, A.D. Boyd, G. Harvey, J. Joo, The social dimensions of smart meters in the United States: Demographics, privacy, and technology readiness, Energy Res. Soc. Sci. 55 (2019) 189–197. https://doi.org/10.1016/j.erss.2019.05.003.

[4] L. Wen, K. Zhou, S. Yang, L. Li, Compression of smart meter big data: A survey, Renew. Sustain. Energy Rev. 91 (2018) 59–69. https://doi.org/10.1016/J.RSER.2018.03.088.

[5] D. Kolokotsa, The role of smart grids in the building sector, Energy Build. 116 (2016) 703–708. https://doi.org/10.1016/J.ENBUILD.2015.12.033.

[6] J. Leiva, A. Palacios, J.A. Aguado, Smart metering trends, implications and necessities: A policy review, Renew. Sustain. Energy Rev. 55 (2016) 227–233. https://doi.org/10.1016/j.rser.2015.11.002.

[7] J.H. Nord, A. Koohang, J. Paliszkiewicz, The Internet of Things: Review and theoretical framework, Expert Syst. Appl. 133 (2019) 97–108. https://doi.org/10.1016/j.eswa.2019.05.014.

[8] M. Jia, A. Komeily, Y. Wang, R.S. Srinivasan, Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications, Autom. Constr. 101 (2019) 111–126. https://doi.org/10.1016/J.AUTCON.2019.01.023.

[9] B. Diène, J.J.P.C. Rodrigues, O. Diallo, E.H.M. Ndoye, V. V. Korotaev, Data management techniques for Internet of Things, Mech. Syst. Signal Process. 138 (2020). https://doi.org/10.1016/j.ymssp.2019.106564.

[10] A.F. Meyabadi, M.H. Deihimi, A review of demand-side management: Reconsidering theoretical framework, Renew. Sustain. Energy Rev. 80 (2017) 367–379. https://doi.org/10.1016/j.rser.2017.05.207.

[11] P. Warren, A review of demand-side management policy in the UK, Renew. Sustain.

Energy Rev. 29 (2014) 941–951. https://doi.org/10.1016/j.rser.2013.09.009.

[12] I. Lampropoulos, W.L. Kling, P.F. Ribeiro, J. Van Den Berg, History of demand side management and classification of demand response control schemes, IEEE Power Energy Soc. Gen. Meet. (2013) 1–5. https://doi.org/10.1109/PESMG.2013.6672715.

[13] L. Gelazanskas, K.A.A. Gamage, Demand side management in smart grid: A review and proposals for future direction, Sustain. Cities Soc. 11 (2014) 22–30. https://doi.org/10.1016/j.scs.2013.11.001.

[14] DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast), Off. J. Eur. Union. 153 (2010) 13–35.

[15] Z. Belafi, A. Gelesz, A. Reith, Investigation on the differences between LEED , BREEAM and Open House assessment systems by means of two Hungarian case studies, in: SB13 Munich, Implement. Sustain. - Barriers Chances, Fraunhofer IRB Verlag, 2013: pp. 32–39.

[16] T. Hong, D. Yan, S. D'Oca, C. fei Chen, Ten questions concerning occupant behavior in buildings: The big picture, Build. Environ. 114 (2017) 518–530. https://doi.org/10.1016/j.buildenv.2016.12.006.

[17] C. Turner, M. Frankel, Energy Performance of LEED ® for New Construction Buildings, New Build. Inst. (2008) 1–46.

[18] A. Mahdavi, C. Pröglhöf, User behaviour and energy performance in buildings, 6. Int. Energiewirtschaftstagung an Der TU Wien. (2009) 1–13.

[19] Z. Deme Belafi, Analysis and Modelling of Occupant Behaviour to Support Building Design and Performance Optimisation (PhD Thesis), Budapest University of Technology and Economics., 2018.

[20] D. Yan, W. O'Brien, T. Hong, X. Feng, H. Burak Gunay, F. Tahmasebi, A. Mahdavi, Occupant behavior modeling for building performance simulation: Current state and future challenges, Energy Build. 107 (2015) 264–278. https://doi.org/10.1016/j.enbuild.2015.08.032.

[21] Z. Belafi, T. Hong, A. Reith, A LIBRARY OF BUILDING OCCUPANT BEHAVIOUR MODELS REPRESENTED IN A STANDARDISED SCHEMA, Energy Effic. 12 (2019) 637–651.

[22] S. D'Oca, T. Hong, J. Langevin, The human dimensions of energy use in buildings: A review, Renew. Sustain. Energy Rev. 81 (2018) 731–742. https://doi.org/10.1016/j.rser.2017.08.019.

[23] T. Hong, S.C. Taylor-Lange, S. D'Oca, D. Yan, S.P. Corgnati, Advances in research and applications of energy-related occupant behavior in buildings, Energy Build. 116 (2016) 694–702. https://doi.org/10.1016/j.enbuild.2015.11.052.

[24] H. Yoshino, T. Hong, N. Nord, IEA EBC Annex 53: Total Energy Use in Buildings – Analysis and Evaluation Methods, Energy Build. (2017).

[25] H. Polinder, M. Schweiker, A. Van Der Aa, K. Schakib-Ekbatan, V. Fabi, R. Andersen, N. Morishita, C. Wang, S. Corgnati, P. Heiselberg, D. Yan, B. Olesen, T. Bednar, A. Wagner, Final Report Annex 53 - Occupant behavior and modeling, (2013).

[26] TOGETHER, DSM tools for the engagement of the building users, Province of Treviso, 2017.